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Efficient herbicide application to reduce environmental losses

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Efficient herbicide application to reduce environmental losses

by

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CHAPTER 1. GENERAL INTRODUCTION

Background

Herbicides can be an important component for weed control in profitable crop production when selected and used properly. When herbicides are incorrectly applied, however, losses to the atmosphere, surface water, and ground water can be the result. Banding as opposed to broadcast application can reduce herbicide input, but losses of herbicides to the atmosphere during spray application can still be substantial, particularly on windy days (Tremwel, 1985). In addition, herbicide applied directly to crop residue is subject to greater volatilization losses (Burt, 1974; Mastbergen, 1987). Crop residue with conservation tillage reduces water and sediment losses, and thus can be an effective tool for reducing herbicide runoff losses, although herbicides surface applied to crop residue may be subject to greater volatilization and runoff losses (Baker et al., 1982; Baker and Johnson, 1979; Kenimer et al., 1987; Laflen et al., 1978).

With greater amounts of residue being left on the soil surface with conservation tillage, a problem arises of not being able to uniformly distribute or incorporate herbicides within the soil profile with tillage without destroying some of the residue (Colvin et al., 1981). In some cases this has resulted in higher herbicide application rates, thus resulting in increased herbicide losses to surface and ground waters

(Hallberg, 1986).

Incorporation of herbicides into the soil profile can significantly reduce losses due to runoff, volatilization, and photodecomposition and possibly runoff. Incorporation likewise often increases the effectiveness of weed control, since there is a higher probability that the herbicide will come in contact with the weed seedling or seed. With uniform placement of herbicide, there should be less chemical required for effective weed control.

Erbach et al. (1976b) found greater weed control when herbicides granules were uniformly distributed within the soil profile. Uneven applications from commercial granule applicators theoretically required 2 to 4 times the rate necessary for weed control when compared to an even distribution of herbicide granules.

In a leaching study, Kay (1989) studied the effects of ridge tillage and application methods on agricultural chemical leaching by using leachate collectors placed 47 cm below the soil profile. Herbicides applied in the field study included metolachlor and atrazine. Kay found that broadcast application of both herbicides resulted in significantly higher percentage losses compared to band application during a 10 cm rainfall event. The maximum percentage of band applied atrazine that was lost with drainage water for the ridge-tilled plots was 0.55.

Since the goal of conservation tillage is to leave as much residue on the soil surface as possible to prevent erosion, incorporation of herbicides without reducing the surface residue is a major stumbling block. Recent and past research has considered new methods of applying herbicides uniformly in the soil profile while destroying as little of the crop residue as possible (Bode and Gebhardt, 1969; Dawelbeit, 1983; Dowler and Houser, 1970; Ehmke, 1984; Fenster et al., 1962; Khalifa et al., 1983;

Solie et al, 1983; Wooten and Mcwhorter, 1961a and 1961b; Wooten et al., 1966).

Problem Statement

Considering the facts above, a herbicide band application system that would allow incorporation of herbicides, without spraying and without destroying the crop residue on the surface, would be an effective herbicide management tool. By using a point-injector cylinder with several spokes that poke through the soil (or crop residue, in the case of conservation tillage), herbicides could be accurately placed in the soil to give a pattern uniformly covering a specific banded area. This point injection system could be effective then in reducing herbicide inputs and losses to the environment during and after application.

Objectives

With an overall goal of efficiently applying herbicides to reduce environmental losses, the objectives of this study are as follows:

1. To develop and implement the design for a point injection system that can:
    (a) inject herbicides into the soil profile at a desired position without spraying,
    (b) incorporate the herbicides in a single pass through the field, and
    (c) leave the residue on the soil surface (with conservation tillage) virtually undisturbed.
2. To evaluate use of this herbicide point injection system on herbicide persistence in the soil, and on weed control under field conditions.

3. To determine the effects of point injection on herbicide concentrations and losses in surface runoff water and sediment and on herbicide leaching.

CHAPTER 2. LITERATURE REVIEW

Herbicide Properties

Herbicides have various properties that must be considered when predicting their fate in and on the soil. No single chemical property indicates how herbicides are lost to the atmosphere, surface water, or ground water. Four important properties which are highly correlated with herbicide fate include persistence, vapor pressure, soil adsorption, and solubility. These properties dictate the method in which herbicides should be applied so to reduce losses to the environment. Table 2.1 shows values for these properties for the chemicals used in this study (Weed Science Society of America, 1983; Soil Conservation Service, 1983; Cooperative Extension Service, 1989).

Persistence

When a herbicide is applied, it is important to know how long it will remain in the soil. This is known as its persistence (see Table 2.1). The persistence of a herbicide is of great importance when considering environmental issues. For example, herbicides that are water soluble, not strongly held to soil particles, and have a long persistence are more likely to leach into the ground water. Carsel and Smith (1987) define a persistent compound as one that does not hydrolyze or biodegrade readily, has a low

Table 2.1: Herbicide properties[a]

Herbicide	Solubility (ppm at 25°C)	Vapor Pressure at 25°C (Pa x 10^{-4})	Sorption Coefficient K_{OC}, (ml/g)	Soil Persistence (months)
Alachlor	242	29	120	1-2
Atrazine	33	.87	160	2-8
Butylate	45	17300	540	1-1.5
Cyanazine	171	.0055	168	2-3
EPTC	370	45300	280	1.5-2
Propachlor	580	306	420	1-1.5
Trifluralin	.00003	146	7300	3-6

[a]Weed Science Society of America, 1983; Soil Conservation Service, 1983; Cooperative Extension Service, 1989

vapor pressure, has a high adsorption coefficient, and has a low potential to leach to the ground water. A nonpersistent pesticide is defined as one that hydrolyzes or biodegrades readily, has a high vapor pressure, is highly water soluble, has a low adsorption coefficient, and has a high potential to move to the ground water.

Persistence is typically quantified in terms of the amount of time it take one-half of the initial herbicide to disappear. This is known as the herbicide's half-lives. Herbicides with long half-lives may carryover and cause damage to the next crop, while those whose half-lives are very short may not persist long enough to provide the necessary weed control (Koskinen and Harper, 1984).

Variations in persistence are attributed to such factors as: herbicide application rate and formulation, soil type, soil-water content, temperature, soil pH, soil clay content and organic matter, and other factors (Ogle and Warren, 1954). These factors determine how much photochemical, microbiological, and chemical transformation of herbicides takes place in soil. Photolysis or photodegradation typically takes place in the top millimeter of soil (Herbert, 1987); microbial degradation is a major factor in the root zone; and chemical decomposition can take place throughout (i.e. the root zone, the vadose zone, and the saturated zone or aquifer). In a study of the behavior of atrazine and cyanazine in soil with varying pH levels, Blumhurst (1989) found that the degradation of cyanazine decreased as the soil pH decreased. Microbial degradation was the major contributing factor in neutral to slightly basic soils, while chemical degradation was greater in a low pH soil.

Conditions that increase the soil microbial activity will increase the herbicide degradation, thus decreasing the persistence of a herbicide. These conditions include increased pH, soil-water content, soil temperature, and organic matter content (Soil Conservation Service, 1983). Considering these conditions, Walker (1974, 1976, 1978, 1987) has developed a computer program for modeling the persistence of herbicides in the soil. His model combines the effects of soil temperature and soil moisture content on the rates of herbicide loss. The input variables include maximum and minimum air temperature and rainfall from available weather data. Walker (1976) evaluated the effect of soil temperature and soil moisture content on the persistence of the herbicides simazine and prometryn. The half-life for both herbicides decreased as the soil moisture increased. The rate of degradation also increased as the initial herbicide concentration decreased and as the temperature increased.

Herbicides that are repeatedly applied to a specific field site have been known to decrease the persistence of those herbicides (Tuxhorn et al., 1986; Ankumah, 1988; Mueller, 1988; Bean, 1986). Ankumah discovered that four days after applying EPTC, 70% of that applied was degraded in the soil that had received 1, 2, 3, or 4 consecutive years of EPTC applications, while for the soil without prior EPTC treatment only 30% was degraded. When a herbicide persists from one growing season to the next, and if the next crop planted is susceptible there is potential for crop injury. Tillage is sometime recommended when carryover is considered to be a potential problem.

Vapor Pressure

Vapor pressure can be defined as "the pressure exerted when a solid or liquid is in equilibrium with its own vapor", and the vapor pressure is a function of the substance and of the temperature (Weast, 1988). Vapor pressure for a given herbicide increases as temperature increases. Volatilization losses are strongly affected by the vapor pressure of a herbicide. As the vapor pressure increases, the volatility of a herbicide also increases. According to Koskinen and Harper (1984) the greatest potential for volatilization losses occurs with herbicides that have a vapor pressure greater than 10^{-2} Pa. Vapor pressures for those chemicals used in this study are shown in Table 2.1. Note that incorporation is recommended for both butylate and EPTC (due to their high vapor pressures) to reduce volatilization losses, especially when applied on a wet soil surface (Weed Science of America, 1983).

The Henry's Law constant is often used to indicate the relative volatility of a herbicide. This constant is defined as "the ratio of the partial pressure of a compound in air to the concentration of the compound in water at a given temperature under equilibrium conditions" (Montgomery and Welkum, 1990). Given the vapor pressure and solubility of a herbicide, the Henry's law constant (K_h) can be calculated as:

$$K_h = \frac{PxS}{760xFW} \tag{2.1}$$

where:

Table 2.2: Volatilization rate relative to Henry's law constants[a]

K_h $(atm \cdot m^3/mol)$	Volatilization Rate
$K_h > 10^{-3}$	Rapid
$10^{-5} < K_h < 10^{-3}$	Fast
$10^{-7} < K_h < 10^{-5}$	Slow
$K_h < 10^{-7}$	Negligible

[a]Lyman et al. (1982)

- K_h = Henry's law constant $(atm \cdot m^3/mol)$
- P = Vapor Pressure (mm Hg)
- S = Solubility (g/L)
- FW = Formula Weight

Lyman et al. (1982) estimated the relative volatility of a substance by using the Henry's law constant as shown in Table 2.2.

Henry's law constant can also be specified as a dimensionless number:

$$K'_h = \frac{K_h}{RxK} \qquad (2.2)$$

where:

- K'_h = Henry's law constant (dimensionless)
- K_h = Henry's law constant $(atm \cdot m^3/mol)$
- K = Temperature of water (degrees Kelvin)
- R = Ideal gas constant (8.20575 x $10^{-5} atm \cdot m^3/mol \cdot K$)

Soil Sorption

The term sorption encompasses adsorption, desorption, ion exchange, and the absorption or partitioning process (Wauchope, 1989). Soil adsorption relates to the removal of herbicides from the air or water and subsequent attachment to the soil surface or into the soil matrix. Adsorption is the process by which substances penetrate into the interior of soil materials or roots, while desorption is just the opposite. Ion exchange relates to ionic pesticides that are held in the soil by chemical charges at the ion exchange sites (Hornsby, 1989). The cation-exchange capacity (CEC) of a soil is a good indicator of how much pesticide can be held. Course-textured soils have a low CECs, whereas fine-textured soils have high CECs. The soil sorption is a primary factor controlling herbicide persistence, activity, and mobility in soils (Wauchope and Koskinen, 1983).

The Freundlich equation is typically used to describe the equilibrium between adsorbed herbicide and the herbicide in solution at the same temperature(Leistra and Dekker, 1976; Boesten, 1987; Wauchope and Koskinen, 1983). Although not always accurate, it is considered one of the best ways to represent adsorption isotherm data. The equation is given as:

$$S = x/m = KC^{1/n} \tag{2.3}$$

where:

- x = mass of substance adsorbed (adsorbate)
- m = mass of adsorbent
- S = x/m = sorbed-phase concentration of substance at equilibrium

- C = concentration of substance in solution at equilibrium
- K and n are constants.

Linear, equilibrium sorption (n=1) can be represented by:

$$S = x/m = KC \tag{2.4}$$

or

$$K = S/C. \tag{2.5}$$

K is often called the 'adsorption coefficient' or 'partition coefficient' for a particular soil or sediment. Although it is easier to work with the linear form of the equation, herbicide sorption usually has a nonlinear relationship with solution concentrations(Koskinen and Harper, 1984). Equation 2.4 can be a satisfactory approximation for Equation 2.3 as long as the value for n stays close to 1 (Hamaker and Thompson, 1972).

The Freundlich equation can be a useful tool in predicting the adsorption capacity of a herbicide onto a soil. It is generally recognized that for most herbicides, concentrations in the sediment phase are much higher than those in the water phase. Those herbicides that are strongly sorbed (higher K values) are mainly lost with sediment, while those herbicides that are weakly to moderately sorbed (lower K values) are lost mainly in surface runoff water. Soils with higher organic matter and clay content will have higher K values for a herbicide. Fawcett (1989) indicates that these soils generally require higher herbicides rates, and those soils with low organic matter and clay content may need lower rates to reduce the risk of crop injury.

Soil organic carbon content may be the best single predictor of pesticide sorption. "Researchers have reported that for a given pesticide, the sorption coefficient normalized with respect to soil organic carbon content is essentially independent of soil type" (Rao and Jessup, 1983). This sorption coefficient is defined as follows:

$$K_{OC} = \left(\frac{K}{\%OC}\right) x100 \tag{2.6}$$

where:

- K_{OC} = Normalized sorption coefficient
- K = Sorption coefficient
- %OC = % Organic carbon in the soil

Herbicides that bind strongly to organic carbon typically have low solubilities, while those with low tendencies to adsorb onto organic particles have high solubilities (Montgomery and Welkum, 1990). K_{OC} values for the herbicides specified earlier are found in Table 2.1.

Wauchope and Koskinen (1983) state that soil adsorption data can be summarized into four generalizations:

1. Temporary equilibrium is established between adsorbed and solution herbicide states.
2. Adsorption correlates with soil organic carbon content.
3. Adsorption is correlated with the escaping tendency of the herbicide in water (Scott et al., 1974).
4. The Fruedlich equation fits the data.

Several computer models for determining the movement of pesticides in the soil have used these same generalizations (Leistra and Dekker, 1976; Leistra, 1977; Boesten, 1987; Wagnet and Rao, 1985).

Helling (1971) used multiple linear regression analyses to study the mobilities of 12 pesticides on 14 soils. Mobility of nonionic compounds was found to be inversely related to adsorption of similar compounds, field moisture capacity, organic matter and clay contents, and cation-exchange capacity. Soil pH was inversely related to the mobility of acidic compounds.

Solubility

"Solubility of one liquid in another is the mass of a substance contained in a solution which is in equilibrium with an excess of the substance" (Weast, 1988). More simply put, it is the amount of material which can dissolve in water or another liquid. Although solubility is an indication of the movement of soil-applied herbicides in the aqueous phase, adsorption is usually more of a controlling factor. For herbicides that have a high water solubility, there can be a higher probability of leaching losses, but this can not be considered to be true in all cases. Some chemicals may be very soluble but due to their high soil sorption will not show up in runoff or leaching waters. Other herbicides may be very insoluble yet very mobile (Wauchope, 1989).

Herbicide Losses

Understanding the herbicide properties is important when looking at how herbicides can be lost. The highest losses of herbicides can be attributed to volatilization, degradation, leaching, and surface runoff (Leonard et al., 1976; Wagnet, 1986;

Leonard et al., 1987; Ogle and Warren, 1954; Koskinen and Harper, 1984). Factors and processes that affect herbicide losses in the soil are shown in Figure 2.1. Several computer models have been developed to predict these losses (Leonard et al., 1987; Wagnet, 1986; Nose, 1987; Walker, 1987; Walker and Barnes, 1981).

Ogle and Warren (1954) in a study on the fate of herbicides, concluded that the fate of herbicides applied to soil is fourfold:

1. Breakdown, either microbial or chemical.

2. Leaching out of the soil.

3. Retention in the soil in an active or inactive form.

4. Volatilization from the soil.

It should be noted that adsorption, degradation, and volatilization will all decrease the amount of herbicide available in the soil profile for runoff and leaching losses. Typically less than 0.5 percent of herbicide that is applied is lost from the agricultural fields with surface runoff unless a severe rainfall occurs with 1-2 weeks after application (Wauchope, 1978).

Volatilization

Herbicides can be widely dispersed into the environment by volatilization and air transport. The major factor influencing volatilization is the herbicide's vapor pressure. The rate of movement away from the evaporating surface and the rate of movement to the surface of the soil are also significant factors. Soil and climatic variables then that affect these factors will affect the volatilization rate (Spencer et al., 1973).

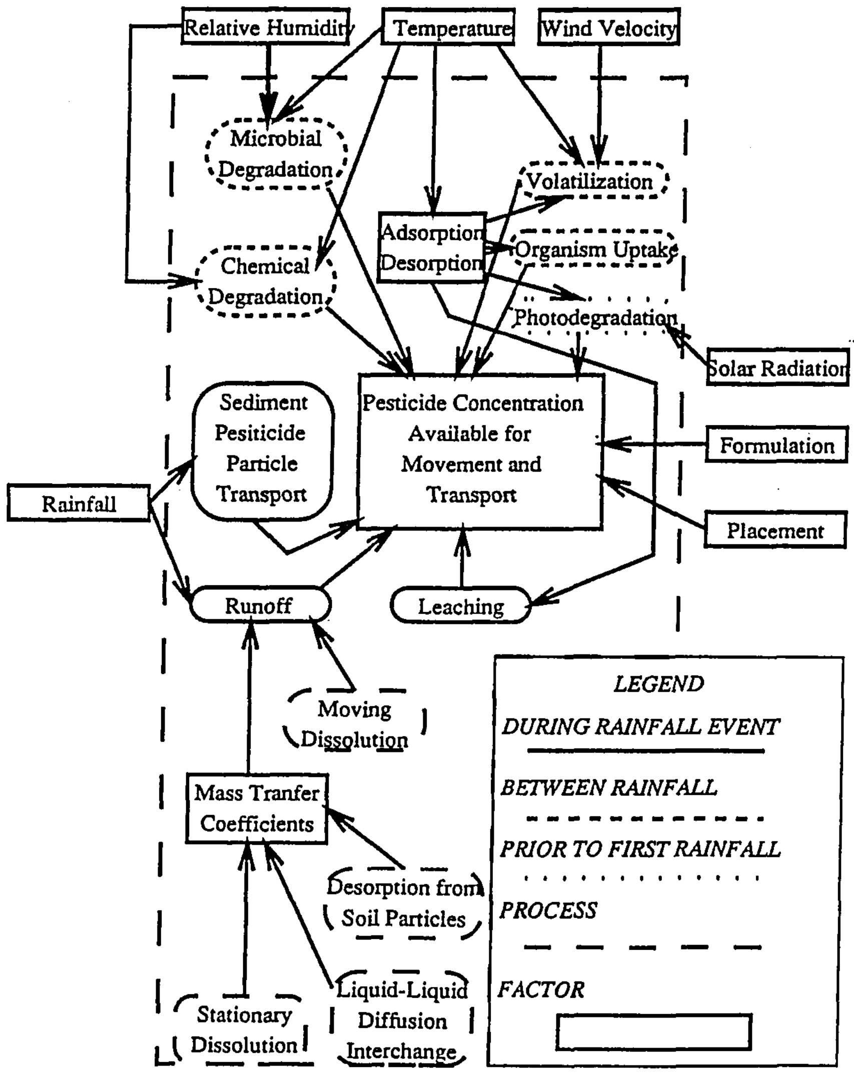

Figure 2.1: Herbicide losses in the soil

Volatilization of soil incorporated pesticides is dependent on pesticide concentration applied to the soil, temperature, soil water content, and soil sorption. Typically, volatility increases as temperature and soil moisture increase (Koskinen and Harper, 1984; Glotfelty et al., 1984). Incorporation of a pesticide affects the distance that it must move before volatilization can take place (Leonard et al., 1976). The percentage of herbicide lost is also a function of the resistance of the herbicide to degradation. If a pesticide degrades quickly, there is less chemical left to volatilize.

Volatilization of a herbicide that is surface applied is dependent on the rate of movement away from the soil or residue surface and herbicide vapor pressure. Whereas, for those that are incorporated volatilization depends upon the rate of movement through the soil to the vaporizing surface (Spencer and Cliath, 1973). This movement through the soil to the surface takes place by mass flow in water and by diffusion.

> Pesticides volatilize faster from wet soils than from dry soils primarily because the presence of water increases the vapor pressure of the pesticide by competing for adsorption sites, but the mechanism of enhanced pesticide volatilization by mass flow in water moving to the surface for evaporation can also contribute to the greater volatilization from wet than from dry soil (Spencer and Cliath, 1973, p. 28).

Mayer et al. (1974) developed several mathematical equations for predicting volatilization of soil-incorporated pesticides. Diffusion laws were used to predict the movement of pesticides to the soil surface for replacing that lost by volatilization.

Jury et al. (1987) used a screening model to predict volatilization losses of 20 pesticides. Volatilization was found to be dependent upon the Henry's Law constant, K_h. This constant is related to the extent to which the air boundary layer restricts volatilization from soil. The air boundary layer is defined as a "stagnant layer connecting the soil and air through which the organic chemical and water vapor must move to reach the atmosphere." Those pesticides with a dimensionless K_h value of 2.65 x 10^{-5} and higher showed decreasing volatility with time, and were not affected by water evaporation. Those pesticides with a K_h value lower than 2.65 x 10^{-5} tended to move to the surface layer faster than they could volatilize. Therefore when water evaporation would take place, the pesticide concentration at the surface would increase and the volatilization rate would also increase with time. Spencer et al. (1988) used two pesticides with widely differing Henry's Law constants to verify this screening model. Their results verified that a pesticide with a low K_h value accumulated at the surface and increased volatility. This was controlled by the boundary layer thickness and the water evaporation rate. It was noted that this could increase the chances for photolysis and runoff to surface water. The volatilization of the pesticide with the higher K_h value was controlled by movement within the soil.

Tremwel (1985) collected data on the volatilization, washoff, and persistence of herbicides broadcast sprayed on residue covered and bare soil plots. "For alachlor, atrazine, and propachlor, respectively, the estimated amounts volatilized from the residue covered soil in the first seven days were 11.8, 8.4, and 8.9 percent of what was applied to the field. For bare soil 1.1, 0.4, and 2.8 percent was estimated to have volatilized." Alachlor and propachlor losses were the highest during the first few hours following application.. Higher residue cover on the soil surface greatly decreases the initial amount of chemical that reaches the soil surface (Banks and Robinson, 1982).

Burt (1974) and Mastbergen (1987) also found that herbicides applied directly to crop residue were subject to greater volatilization losses. Burt concluded in a volatility study that "atrazine volatility is a major factor for atrazine dissipation when applied to foliage but not when applied to the soil." Mastbergen (1987) found losses due to volatilization and/or degradation during the 24 hours between herbicide application and simulated rainfall to be 36.4, 11.7, 30.1, 7.9, 28.9, and 0 percent, respectively, for acetachlor EC, acetachlor MT, alachlor EC, alachlor MT, metolachlor, and cyanazine. These losses were found to be highly dependent on vapor pressures and formulation.

For effective weed control proper application of herbicides is important. Proper application includes uniform application of herbicide to increase contact with the weed seedling or seed, and incorporation into the soil profile so to minimize herbicide volatilization and photodecomposition.

Degradation

Losses of herbicides to microbiological, photochemical, and chemical pathways of transformation are collectively termed degradation (Wagnet and Roa, 1985). Photodegradation is of little significance for those herbicides that are placed below the soil surface, and may not be significant for those herbicides placed on the soil surface depending on their susceptibility to light breakdown (Hebert, 1987). Degradation has typically been described using a first-order differential equation

$$\frac{dC}{dt} = -kC \tag{2.7}$$

where C = amount, t = time, and k is the first order rate constant (Walker and Thompson, 1977; Wagnet and Rao, 1985; Wagnet, 1986; Leonard et al., 1987; Nose, 1987; Reyes and Zimdahl, 1989; Nash, 1990). When integrating the differential equation above, a degradation rate equation is the result:

$$C = C_o e^{-kt} \tag{2.8}$$

where C = herbicide amount on day t, C_o = initial herbicide amount (t = 0), e = 2.718, and k = dissipation rate constant. The term dissipation is a collective and more empirical term relating to the disappearance of a herbicide by any number of unquantified pathways (Wagnet and Roa, 1985). Models such as GLEAMS (Leonard et al., 1987) and PRZM (Carsel et al., 1985) typically use this first-order rate equation to estimate pesticide degradation.

The rate constant for a herbicide (in days) can be calculated from the equation:

$$C_{1/2} = C_o e^{-k * t_{1/2}} \tag{2.9}$$

where $C_{1/2}$ = 50 percent of the initial herbicide amount, $t_{1/2}$ = time in days for 50 percent of the herbicide to dissipate, and k is the rate contant.

Nash (1988) suggested a computational approach in which the dissipation rate constant could be defined in terms of several of the transformation and degradation processes. In this case, the first-order equation would look like this:

$$C = C_o e^{(k_a + k_p + k_h + k_b + k_o + k_r + k_l + k_f + k_c + k_{bcf} - k_d - k_e)t} \tag{2.10}$$

where $k_a, k_d, k_h, k_b, k_o, k_r, k_l, k_f, k_c, k_{bcf}, k_d, k_e$ = volatilization, photolysis, hydrolysis, biodegradation, oxidation, reduction, leaching, diffusion, complexation, bioconcentration factor (bioaccumulation by soil fauna and flora), desorption, and bioelimination rates, respectively. Since many of these processes are of little importance or significance, they can be omitted. Most researchers have not used this approach, and therefore have lumped together these processes into a single dissipation rate constant,

k. This equation does show some losses that may occur before microbial and chemical degradation take place. These include the categories of volatilization losses, soil sorption, and soil leaching. Each of these areas are discussed in more detail in the other sections.

The kinetics of microbial herbicide degradation in soil are affected by the quantity and availability of the herbicide, the quantity and type of microorganisms or enzyme systems capable of degrading the pesticide, and the activity level of degrading microorganisms as influenced by environmental conditions (Koskinen and Harper, 1984). Chemical decomposition reactions such as hydrolysis will also lead to dissipation of the applied herbicides. More research has been conducted on microbial degradation as compared to chemical decomposition, and therefore its effect on herbicide degradation tends to be better understood.

"The single most important factor affecting herbicide dissipation is the herbicide itself" (Nash, 1990). Some herbicides dissipate primarily by microbial activity, whereas other herbicides may dissipate by chemical reactions. Soil temperature and soil moisture are major factors that influence dissipation due to microbial activity. Soil type and soil pH are also important factors, but usually do not have the effect that soil temperature and soil moisture do. Dissipation is typically higher for warm and moist soils due to the increased microbial activity. Increased organic matter content may also increase microbial degradation. Microbial activity is the highest in the root zone closest to the soil surface. The microbial population decreases exponentially with soil depth. Below the root zone, herbicides are more likely to be transformed chemically by hydrolysis or by some oxidation or reduction process.

Walker and Thompson (1977) found that the degradation of simazine, linuron and propyzamide followed first-order kinetics. The rate of microbial degradation for linuron was correlated to soil organic matter and highly correlated to clay content, soil respiration, and the adsorption distribution coefficient. With simazine, degradation was found to increase at a lower soil pH. This was attributed to an increase in the rate of non-biological hydrolysis.

Nose (1987) suggested a multi-site decay model be used to represent the decay of a pesticide when incorporated into the soil. His argument was that pesticides are distributed to several independent sites, where decay occurs at different rates. The following equations were suggested:

$$C = \sum_n C_n e^{-k_n t} \tag{2.11}$$

$$C_o = \sum_n C_n \tag{2.12}$$

where:

- C_n = initially distributed amount
- k_n = decay rate constant in the n^{th} site.

If $k_1 = k_2 = k_3 = ... = k_n$ then the equation becomes the first-order decay equation (Equation 2.8).

The moisture content in the soil was used by Walker (1974, 1976, 1987) and Walker and Barnes (1981) to calculate the effects of moisture on herbicide degradation. The following empirical equation was used to calculate the half-life ($t_{1/2}$) of a herbicide at a given moisture content (MC):

$$t_{1/2} = aMC^{-b}. \tag{2.13}$$

The constants, a and b, were derived from laboratory incubation experiments. The Arrhenius equation was also used to relate the half-life to temperature:

$$\log \frac{t_{1/2}}{t_{1/2}'} = \frac{\Delta E}{4.575}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \tag{2.14}$$

where $t_{1/2}$ and $t_{1/2}'$ are half-lives at temperatures T_1 and T_2, and ΔE is the activation energy. The model using these equations did a good job of predicting the degradation of several herbicides in field situations.

It should be noted that field-measured half-lives are generally shorter than those measured under controlled laboratory conditions (Wagnet and Rao, 1985). This is in part due to the fact that the first-order degradation rate coefficient is a function of the environmental factors affecting the microbial system.

Nicholls et al. (1982) used four different first-order degradation methods to determine the degradation of atrazine and metribuzin in a fallow soil. The four methods included the first order equation with:

1. a single mean rate constant (k_1).
2. a laboratory rate constant with diurnal temperature fluctuations.
3. a laboratory rate constant without diurnal temperature fluctuations.
4. Walker and Barnes (1981) persistence model mentioned above.

Comparison of the four methods showed that prediction of degradation rates in the field from laboratory data can be satisfactory with some compounds. The diurnal temperature fluctuations, when included in the model, did give better predictions.

A mathematical model was developed by Reyes and Zimdahl (1989) to determine the degradation of trifluralin in soil. The model used described the concentration-time relationship as the sum of the first- and second-order differential rate equations:

$$dC = -(k_1 C + k_2 C^2). \tag{2.15}$$

The following equation is the result after integrating equation 2.15:

$$\frac{c(k_1 + k_2 C_o)}{C_o(k_1 + k_2 C)} = e^{-k_1 t} \tag{2.16}$$

where:

- t = time
- C_o = amount at t = 0
- k_1 and k_2 = constants.

When comparing this model with the commonly used first-order model, the biexponential equation (Equation 2.16) described the degradation data better for 15 out of 25 soil-site combinations.

When studying the metabolism of alachlor and propachlor in suspension, Novick et al. (1986) revealed that mineralization, due to microbial activity, was a major means for the destruction of propachlor but not for alachlor. Less than 8 percent of the alachlor was mineralized in 30 days while in soil suspension, while microorganisms in suspension with propachlor mineralized as much as 63 percent of the original amount. Since alachlor was not mineralized and persisted for longer periods, the possibility for transport to another site in a field situation could be high.

A screening model developed by Jury et al. (1987) was used to determine whether a pesticide would reach the ground water after surface application. The model assumptions included steady water flow, equilibrium linear adsorption, and depth-dependent first-order microbial degradation. Two pollution scenarios were used. A low pollution scenario represented a soil with high organic matter, high volumetric water content, and a deep (1 m) biological zone. The high pollution condition included a soil with low organic carbon, low water content, and a shallow biological zone. By assuming that the residual pesticide mass was less than the initial pesticide mass added, "the model prediction was shown to reduce to a linear inequality between the organic carbon partition coefficient K_{OC} and the biochemical half-life $t_{1/2}$." Jury et al. (1987) concluded that such a screening model would be appropriate for classifying pesticides for pollution potential, but that soil and management practices should also be considered.

The effects of repeated applications of EPTC on the rates of degradation due to degrading microorganisms was researched by Moorman (1988). "Increased rates of metabolism of EPTC were apparently responsible for the increased rates of degradation rather than increased population of microbial degraders." This was only true for soils that were treated with EPTC for over six years.

Leaching

When herbicides move down through the soil profile with water it is called leaching. Studies have shown that many commonly used herbicides are leached into the ground water (Hallberg, 1986). Leaching of herbicides is affected by the solubility of the herbicide, adsorption of the herbicide in the soil, moisture content of the soil at the time of application, and amounts of evaporation between rains. Herbicide leaching has been found to be inversely proportional to the herbicide adsorption characteristics, field moisture capacity, organic matter and clay content, and cation-exchange capacity, whereas soil pH and water flux tend to be directly related to herbicide leaching (Helling, 1971).

The herbicides with a higher adsorption coefficient move slower through the soil profile than those with lower adsorption coefficients. Greater quantities of water would therefore be required to leach a herbicide with a large K or K_{OC} value to a given depth (Soil Conservation Service, 1983). Keller and Alfaro (1966) conducted as study on the effects of different continuous water application rates on leaching. Their results suggested that leaching losses of herbicides were increased by decreasing the water application rate.

In a leaching study, Wiese and Davis (1964) monitored the herbicide movement in 24 inch soil tubes when applying various amounts of water. Twelve herbicides with varying solubilities and adsorption characteristics were applied in water solutions or suspensions to wet and dry soils. Also, different amounts of water were used with the carrier and for leaching. Those herbicides that had a tendency to leach easily, were not affected by the water application method and leached as deeply as the water penetrated into the soil tubes. The insoluble herbicides moved deeper into the soil column in the wet soil tubes when compared to the dry soil tubes. Greater quantities of water were required to leach these herbicide to a given depth.

When looking at the diffusion of herbicides in the soil profile, Ritter et al. (1973) found that the greatest amount of herbicide movement occurred with high temperatures and high moisture contents. An increase in bulk density tended to decrease the movement for all the herbicide studied.

Tillage has been shown to significantly affect the number of macropores and their effect on herbicide leaching losses (Boddy and Baker, 1990; Mukhtar et al., 1985). Mukhtar et al. (1985) compared the use of a Paraplow treatment with a moldboard plow, a chisel-plow, and a no-tillage treatment. The Paraplow loosened the soil but did not invert the soil surface. Infiltration was increased with the Paraplow due to its deep, surface connected cracks. The increased residue cover with the Paraplow and with the no-tillage treatments prevented surface sealing, thus also increasing the soil water infiltration.

Boddy and Baker (1990) compared conservation tillage effects on nitrate and atrazine leaching. The tillage treatments included moldboard plow, chisel plow, and no-tillage. Soil columns, 20 cm in diameter and 30 cm deep, were collected from each of the tillage treatments. Simulated rainfall was applied to the soil columns approximately 24 h after the chemicals were applied. A total of 7.5 cm of rainfall was applied to all of the columns using variations in timing, duration, and intensity. The results showed that drainage occurred sooner for the chisel plow treatments. Drainage occurred sooner with the high intensity rainfall. Atrazine losses were highest with the chisel plow treatment. The largest loss was 0.089 percent of that which was applied. This occurred during the most intense rain which was preceded by a wetting rain. The highest initial concentration was 11 ppb. Overall, the leaching losses of atrazine for the chisel plow, the no-tillage, and the moldboard plow treatments were 0.082, 0.071, and 0.042 percent, respectively.

Modeling of leaching in the soil profile has been attempted by several researchers (Addiscott, 1977; Addiscott, 1986; Leonard et al., 1987; Carsel et al., 1984; Enfield et al., 1982; Wagnet and Hutson, 1989). A more recent and popular model is the Pesticide Root Zone Model (PRZM). PRZM models pesticide fate and transport in the unsaturated zone or the vadose zone. The vadose zone typically includes the root zone and the unsaturated zone below the root zone. PRZM calculates the pesticide fate and movement using a daily time step with mass balance equations developed for the surface and subsurface zones. The surface zone losses can occur in runoff, percolation to the next zone, sorbed loss with eroded soil, and decay. The subsurface zone losses include plant uptake and percolation in the soluble phase, and decay in both phases (Lorber and Offutt, 1986). Assumptions used in the model include: instantaneous, linear, reversible adsorption described by the adsorption partition coefficient, K_d, and first order decay described by an overall decay rate, k.

In a model by Addiscott's (1977, 1986) the soil solution was partitioned into mobile and retained phases. Only the mobile solution was available for displacement during water movement. In addition, the soil profile was divided into finite layers where water and solutes were partitioned between a mobile and a retained phase.

Runoff

Losses of herbicides from runoff and erosion is of concern both economically for the farmer and environmentally for the general public. A considerable amount of research has been conducted to determine how herbicides are lost during a rainfall event, and how to reduce those losses. Rainfall simulation has been one of the most common methods for studying herbicide losses with runoff water and sediment (Barnett et al., 1967; White et al. 1976; Baker et al., 1978; Barisas et al., 1978; Baker and Laflen, 1979; Trichell et al, 1969; Ahuja, 1982; Ahuja and Lehman, 1983; Mickelson, 1984; Laflen et al., 1991). Several models have also been developed to predict herbicide losses with surface runoff (Heathman et al., 1986; Baker, 1985; Lorber and

Mulkey, 1982; Heathman et al., 1985; Steenhuis and Walter, 1980; Leonard et al., 1979; Laflen et al., 1991; Foster, 1991; Renard et al., 1991).

The rainfall simulation studies have shown that maximum herbicide concentrations in runoff occur early in a rainfall event and decrease during the duration of the simulated storm. Highest losses resulted if the rainfall event occurred shortly after herbicide application as opposed to later. White et al. (1976) found that "surface runoff levels were highest for the first runoff event after herbicide application each year, and initial concentrations were related to the time lapse between herbicide application and the date of the first runoff event," when studying the loss of 2,4-D from a small agricultural watershed. The same comments were made by Baker and Johnson (1979) when researching the runoff losses of alachlor, atrazine, and cyanazine. In this rainfall simulation study, "80 to 90 percent of the average herbicide losses were with water." Conservation tillage systems were found to decrease runoff and erosion (and herbicide losses), although herbicide concentrations in water and/or sediment were sometimes higher for conservation tillage relative to conventional tillage.

Since most herbicides are at least moderately adsorbed to soil, concentrations of herbicides in sediment tend to be higher than those in the water. Haan (1971) conducted a rainfall simulation study looking at the runoff losses of aldrin, dieldrin, and DDT. It was discovered "that the concentration of the pesticides in the eroded soil was on the order of 10 to 30 ppm while that in the runoff water was only 1 to 70 ppb." Similar findings were reported by Baker and Laflen (1979) when studying the effect of wheel tracks and incorporation on runoff losses of surface-applied herbicides. Even though herbicide concentrations in sediment were as much as 4 times higher than in runoff water, 82 to 89 percent of the herbicide losses were in solution. Total losses of alachlor, atrazine, and propachlor were about 3.7 times greater for the plots with wheel-tracks versus those without. The incorporated herbicide plots losses were approximately 3.5 lower than those plots with no incorporation and no wheel-tracks. Therefore herbicides which were incorporated had the lowest runoff losses.

Total losses of those herbicides applied in most of the runoff studies seldom were found to be over 10 percent of that which was applied (Hall et al., 1983; Baker and Laflen, 1979; Baker et al., 1978; Hall et al., 1972; Trichell et al., 1968; Hartwig and Hall, 1980). Hartwig and Hall (1980) stated that "Generally, wettable powder, flowable and dry flowable herbicide losses up to 5 percent of that applied can be expected from fields with a 10 to 15 percent slope. Fields with a slope of 3 percent or less will commonly not have herbicide losses greater than 2 percent of that applied."

Several researchers have studied the mixing effect of rainfall water with the chemical solution in the top soil layer and its relationship to the chemical transfer of herbicides to runoff water (Heathman et al.,1985, 1986;Aluja and Lehman, 1983; Ahuja, 1982; Steenhuis and Walter, 1980; Leonard et al., 1979; Baker, 1980). Heathman et al. (1985) used a non-uniform mixing model to predict the transfer of herbicides to surface runoff. "The model incorporates the varying degree of mixing with depth between rainwater and soil during the chemical transfer process, as well as the effects of infiltration on chemical movement into the soil before and after runoff begins." The adsorption-desorption process for weak to moderately adsorbed chemicals was represented by the equation

$$C_S = \alpha C \tag{2.17}$$

where:

- C_S = concentration of chemical in the adsorbed phase on soil particles

- C = chemical concentration in soil solution
- α = constant.

The degree of mixing between the rainfall and the soil solution was assumed to decrease exponentially with soil depth, starting from the time runoff began:

$$\beta = e^{-bz} \tag{2.18}$$

where:

- β = degree of mixing between rainfall and soil solution
- b = constant
- z = soil depth (maximum depth of soil interaction with rainfall is taken to be less than 2.0 cm).

Most researchers agree that the mixing zone is probably less than 2 cm below the soil surface. "One factor that affects this depth of interaction is the mixing caused by raindrop splash, both temporary suspension of soil and localized high hydraulic pressure areas" (Baker, 1980).

Residue has a major effect on raindrop impact, decreasing the mixing at the soil surface and therefore decreasing potential runoff and erosion losses (Mickelson, 1984; Heathman et al., 1986). Still herbicide losses when herbicides are applied to no-tillage fields can be high due to the high concentration of the herbicides at the soil surface. Residue cover has been shown to increase water infiltration and to decrease erosion and runoff losses (Mickelson, 1984; Baker and Laflen, 1982; Baker et al.,1982; Laflen et al.,1978; Dickey et al., 1984; Kenimer et al., 1987).

Controlling Herbicide Losses

Herbicide losses can be controlled when the correct farming practices are put into place. These practices include leaving more residue on the soil surface (conservation tillage), incorporating herbicides into the soil profile, or placing the herbicide below the soil surface using subsurface injection. Each of these options and their advantages and disadvantages are discussed in more detail in the following sections.

Conservation Tillage

Conservation tillage can be defined as a farming system that leaves at least 30 percent surface residue cover after planting. Conservation tillage systems include no-till or zero tillage, ridge-till, disk/chisel plow, strip-till, slot planting, mulch-till, and reduced-till (Karlen, 1990; Agricultural Age, 1983). Since conservation tillage leaves crop residue on the soil surface, it can protect the soil and the environment by reducing sediment and chemical runoff. It also is effective in retaining surface soil moisture and acts as an insulator for the soil. In order to retain a minimum amount of crop residue on the surface to be considered conservation tillage, the correct individual tillage implements must be selected. The tillage implement used should be a function of the particular soil, the climatic conditions, the residue characteristics, and the farming operation.

Colvin (1981) measured the reduction of surface residue caused by individual tillage implements for a single pass. An example for corn residue showed that following harvest, a field might have a 90 percent surface residue cover. If the farmer fall chisel plowed, spring disked, and planted with double disk openers, there would be approximately 32 percent of the surface covered. When 20 percent or more of the soil surface was covered with residue, Dickey et al. (1984) found that soil erosion was reduced by at least 50 percent in comparison to that for a moldboard plow system. Therefore, a significant amount of soil erosion can be prevented by using a conservation tillage system.

The type of residue that is tilled has a large effect on how much is left on the surface. Siemens and Oshwald (1978) and Dickey et al. (1985) both noted greater soil losses with soybean residue versus corn residue when tilled before rainfall. For example, Siemens and Oshwald noted 40 times the soil losses after 6.35 cm of simulated rain for soybeans residue disked and chiseled compare to corn residue tilled with the same system. The equivalent tillage system left 40 percent less soybean residue relative to corn residue in Dickey's study.

Herbicides that are lost mainly with sediment benefit the most from conservation tillage due to the reduction in soil erosion. Laflen and Colvin (1981) found erosion to be a function of percentage residue cover:

$$Sed = Ae^{-B(RC)} \tag{2.19}$$

where:

- Sed = erosion during a storm from an area with residue cover
- RC = residue cover for the given area
- A = erosion from an area with no residue cover
- e = 2.718
- B = empirical coefficient.

As residue cover increases, erosion during a storm decreases. To simplify predicting soil erosion for conservation tillage, Laflen et al. (1981) proposed using only the percentage residue cover, rather than percentage residue cover, tillage system, and residue weight . A residue factor was developed to derive a C-value for conservation tillage for use with the universal soil loss equation. The residue factor (RF) was given as:

$$RF = e^{-0.05(RC-3)} \tag{2.20}$$

where RC is the percent residue cover.

Runoff and sediment losses have been found to decrease with increase of residue cover for chisel plow tillage and various conservation tillage systems (Baker et al., 1982; Baker and Johnson, 1979; Kenimer et al., 1987; Laflen et al., 1978; Triplett et al., 1978). With greater residue being left on the soil surface with conservation tillage, a problem arises of not being able to uniformly distribute or incorporate herbicides within the soil profile without destroying some of the residue with tillage (Colvin et al., 1981). In some cases this has resulted in higher herbicide application rates, thus resulting in increased herbicide losses into the surface and ground water (Hallberg, 1986).

Residue also acts as a physical barrier over the soil and can intercept surface-applied herbicides. In a rainfall simulation study (Martin et al., 1978), herbicides cyanazine, alachlor, atrazine, and propachlor were applied to corn residue in the laboratory. These herbicides were washed off quickly from the residue, with initially high herbicide concentrations in the runoff. The authors also noted unexplained losses of herbicide which indicated possible volatilization taking place between the time of application and the time of rainfall.

Herbicide losses with water and sediment were found to decrease exponentially with increasing residue cover (Baker et al., 1982):

$$Loss = ae^{-b[residue]}. \tag{2.21}$$

Crop residue was found to significantly reduce the herbicide losses. This was attributed to the delayed and reduced surface runoff. Whether the herbicide was placed on or below the corn residue seemed to have little or no effect on concentrations in the runoff water and sediment under the conditions of their study.

Kenimer et al. (1987) also found runoff and sediment losses decreased with increasing residue cover for chisel plow and no-tillage systems. When compared to chisel plow tillage, the no-tillage system reduced sediment loss and total runoff volume by 98 percent and 92 percent, respectively. Runoff water was the major carrier of both 2,4-D and atrazine. Of the total amount of atrazine applied, 2.9 percent was lost from the chisel plow tillage plots, while only 0.3 percent was lost from the no-tillage plots. For 2,4-D, the losses were 0.3 percent for chisel plow tillage and 0.02 percent for no-tillage.

Surface runoff is not always less when using conservation tillage. The effect conservation tillage has on infiltration will determine to what extent runoff and leaching occurs (Baker, 1987). When comparing no-tillage to a chisel plow treatment and to a residue managed treatment (where the residue was removed, the soil was disked, and the residue was replaced) runoff losses were significantly higher for the no-tillage treatments (Mickelson, 1984). There was a high soil moisture content present before the simulated rainfall began. This tended to decrease infiltration for the no-tillage treatments. The residue managed treatment had the least runoff. This was attributed to the looseness of the soil from tillage and the uniform surface coverage by the corn residue after being reapplied, which prevented the soil from surface sealing. The soil erosion from the no-tillage and the residue managed plots was less than one-half of that from the chisel plowed plots.

Total herbicide losses have been found to be dependent on the time between the application of the herbicide and the rainfall (Ritter et al., 1974; Baker and Johnson, 1979). Rainfall within 24 hours after alachlor and atrazine were applied resulted in losses of 10 and 15 percent of that applied, whereas rainfall two weeks after application resulted in losses of less than 2 percent for both herbicides.

In another rainfall simulation study (Baker et al., 1982), the effects of corn residue and herbicide placement on runoff losses for the herbicides propachlor, atrazine, and alachlor were measured. Application above or below the corn residue had little or no effect on herbicide concentrations in runoff water and sediment. Research plots with no residue showed average herbicide losses of 7 percent of that applied, while those plots with 1500 kg/ha of residue cover had only 1 percent of that applied lost due to delayed and lower volume of runoff.

Crop residue interception and retention of the herbicides can greatly affect volatilization and runoff losses. Wruke (1986) studied the effect of such variables as residue type and amount, amount of rain, time of rainfall occurrence, and herbicide formulation. As expected, the amount of herbicide reaching the soil decreased with increasing residue cover. As much as 60 percent of the herbicide applied was intercepted. Using simulated rainfall, 50 percent of the atrazine applied and 75 percent of the cyanazine applied was removed with 25 mm of rainfall. Both herbicides were more easily removed from the corn residue when compared to wheat or soybean residue. The dry-flowable formulation of cyanazine and the wettable powder formulation of atrazine were found to wash off easier than other formulations.

In contrast, Baker and Shiers (1989) found that formulation of cyanazine did not affect wash off from the corn residue. Also no significant difference in washoff was found between methods of application when using water or oil-water carriers for cyanazine. Most of the wash off occurred during the first one-quarter of the rainfall event for cyanazine, alachlor, and propachlor.

No-tillage has been proven to be an effective system in reducing soil erosion and runoff losses, yet its performance in the field has kept many farmers from using it (Redlin, 1987). Poor yields due to cold soil, compaction, and weed problems are the main reasons (Karlen, 1990). Ridge-tillage has picked up in popularity in states where the rainfall and soil moisture levels are adequate, and where cold soils can become a problem. With ridge-tillage, the plants are planted on a ridge where the residue has been scraped away. Ridges are formed by cultivation once or twice during the growing season. The shape of the ridge and the partial removal of residue from the ridge top helps to warm the soil for the seed bed. Erosion from ridge-till plots was found to be a function of the ridge life (Brown and Norton, 1990). Ridges 0-, 4-, and 8-years of age were exposed to rainfall simulation at at rate of 64 mm/h. "Soil loss and sediment concentration were significantly greater for 0-yr ridges compared to 4- and 8-yr ridges."

Herbicide Placement and Incorporation

Volatile and photodegradable herbicides typically require some form of incorporation to avoid major losses. Without the proper placement of these herbicides in the soil profile they may be ineffective in controlling weeds. Incorporation depth depends on the type of tillage or application device used. Placement depth should be a function of the depth at which the herbicide will be taken up by the weed. The mode of uptake of herbicides by the weeds is at the roots, the shoots, the leaves, or at a combination of these (Barrentine, 1984).

To achieve uniform incorporation of the herbicide in the soil, the incorporation equipment must leave an adequate distribution pattern. Bode and Gebhardt (1969) evaluated various equipment for the incorporation of the herbicide trifluralin. Eight different incorporation implements were compared to determine the distribution of the herbicide in the top soil layer. These implements included a power rotary cultivator, disk harrow, spike tooth drag harrow, Gandy Ro-Wheel, field cultivator, Lilliston rolling cultivator, Adkins-Phelps Mix-a-Product, and Richardson mulch treader. A treatment with surface application but no incorporation was also used. The disk and the power rotary cultivator were run at a 10 cm depth, whereas the other implements were run at a 5 cm depth. The disk concentrated the trifluralin in the top 5 to 7.5 cm while the power rotary cultivator left the highest concentration in the top 2 centimeters. For the other implements, 80 percent of the recovered chemical was located in the top inch. None of these produced a uniform vertical distribution in the tilled area.

Bode et al. (1979) did a similar study looking at herbicide incorporation using two tandem disk harrows having different blade spacings and blade diameters. Treatments included single and double passes with the disks. The results showed that with two passes at an appropriate speed, the herbicides were fairly uniform in the soil. If the soil conditions were good, a single pass gave uniform mixing in the top two inches. Uniform mixing was significantly affected by blade spacing and depth of operation. Blade diameter didn't seem to have much of an effect.

In a herbicide incorporation study using a field cultivator, Dowell et al. (1988) found that 23 cm sweeps with a spacing of 15 cm moving at a speed of 6.4 km/h resulted in the best vertical and horizontal herbicide distribution.

The goal of conservation tillage is to leave as much residue on the soil surface as possible to prevent erosion. Yet, incorporation of herbicides without reducing the surface residue is a major stumbling block. Since several types of herbicides are more effective when accurately placed within the soil profile, research has looked at new methods of application (Dawelbeit, 1983; Khalifa et al., 1983; Solie et al, 1983).

Subsurface placement methods for metribuzin and trifluralin were tested by Khalifa et al. (1983) for controlling growth of rape and forage sorghum in the greenhouse. Five patterns of herbicide distribution in the soil profile were used: (1) surface mixing, (2) subsurface layering, (3) subsurface lines 2-4 cm apart, (4) bands 1 cm wide, 1-3 cm apart, and 7.5-10 cm deep, and (5) bands 1 cm wide, 1-2 cm apart, 2.5 cm and 5 cm below the top mixed layer. No significant differences were found for rape control with metribuzin when using surface mixing, subsurface layering, or subsurface lines 2, 3, or 4 cm apart. One-hundred percent rape control was found with incorporation depths from 2.5-10 cm. With trifluralin applications, complete mixing in the top soil layer significantly controlled sorghum better than subsurface line application methods. Shallow banding of trifluralin for 2.5-5 cm depths were better at controlling sorghum than the depths from 7.5-10 cm. The effectiveness of banding was increased even higher when mixing of the bands also took place. Herbicide placement as deep as 7.5 cm and with band spacing as far apart as 2 cm showed adequate control of the sorghum. The authors encouraged the development of subsurface herbicide injection systems for effective incorporation of herbicides with reduced residue destruction.

Herbicide Soil Injection Devices

Herbicides that are applied to the soil for weed control can be grouped according to their need for mechanical incorporation: (1) is effective if left on the soil surface or incorporated, (2) does not provide adequate weed control when incorporated into the soil, or (3) requires mechanical incorporation (Ross and Lembi, 1985). Incorporation has been shown to provide more consistent weed control results when compared to surface applied herbicides over a period of years. Surface applied herbicides typically rely on rainfall to move them into the soil whereas mechanically incorporated herbicide are mixed or placed in the soil by the specific mechanical device. Mechanical incorporation also can reduce losses due to volatilization and photodegradation on the soil surface while at the same time providing better placement of the herbicide for the control of weeds.

An important goal of conservation tillage is to leave as much residue on the surface as possible to prevent soil erosion. Incorporation of herbicides without reducing the surface residue is difficult with the implements used today (Colvin, 1981). This makes it difficult to use herbicides that need mechanical incorporation in order to be effective for weed control or to reduce environmental losses. Several herbicides are more effective when accurately placed within the soil profile. Some herbicide application equipment has been developed to place the herbicides in the soil profile without destroying much of the crop residue.

One of the first devices developed for subsurface application of herbicides was designed and tested by Wooten and McWhorter (1961a). This device applied liquid

EPTC 5 to 15 cm under the soil profile using a 40 cm wide band of spray approximately 6-mm thick. A side view of the applicator is shown in Figure 2.2. Soil flowed over a concave blade 50 cm in width. A spray boom was placed inside the angled horizontal blade of the applicator. Adjustable angled spray nozzles applied the herbicide as the blade produced an umbrella of soil under the soil surface. Weed control ratings were obtained following the pre-plant application of EPTC at a rate of 5.6 kg/ha. Better control was realized with subsurface application of the herbicide when compared to surface application with rotary hoed incorporation. Using a florescent tracer, the distribution of the soil-applied chemicals were studied. This method showed a poorer distribution for surface applied herbicides followed by a rotary hoe (Wooten et al., 1962).

Wooten and McWhorter (1962) modified their subsurface herbicide applicator to allow them to apply solid herbicide material such as dust or granules. The spray bar was replaced by a perforated tube or by a single outlet tube. A power-take-off driven duster was used to supply the material to the applicators. Both of the applicators were found to give satisfactory band patterns, although the perforated tube seemed to have a better probability of succeeding.

With the desire to increase the versatility and performance of application beyond that which was found with the horizontal blade applicator, Wooten et al. (1966) came up with a new applicator design. This design, called the Stoneville knife-type herbicide injector, deposited a liquid stream of EPTC in a narrow vertical slot created by each knife injector. The injectors were spaced 5 cm apart, with two knives placed in each side of a planting drill. When the spacing of the injectors was greater than 6.4 cm apart, weed control was dramatically decreased. The older horizontal blade

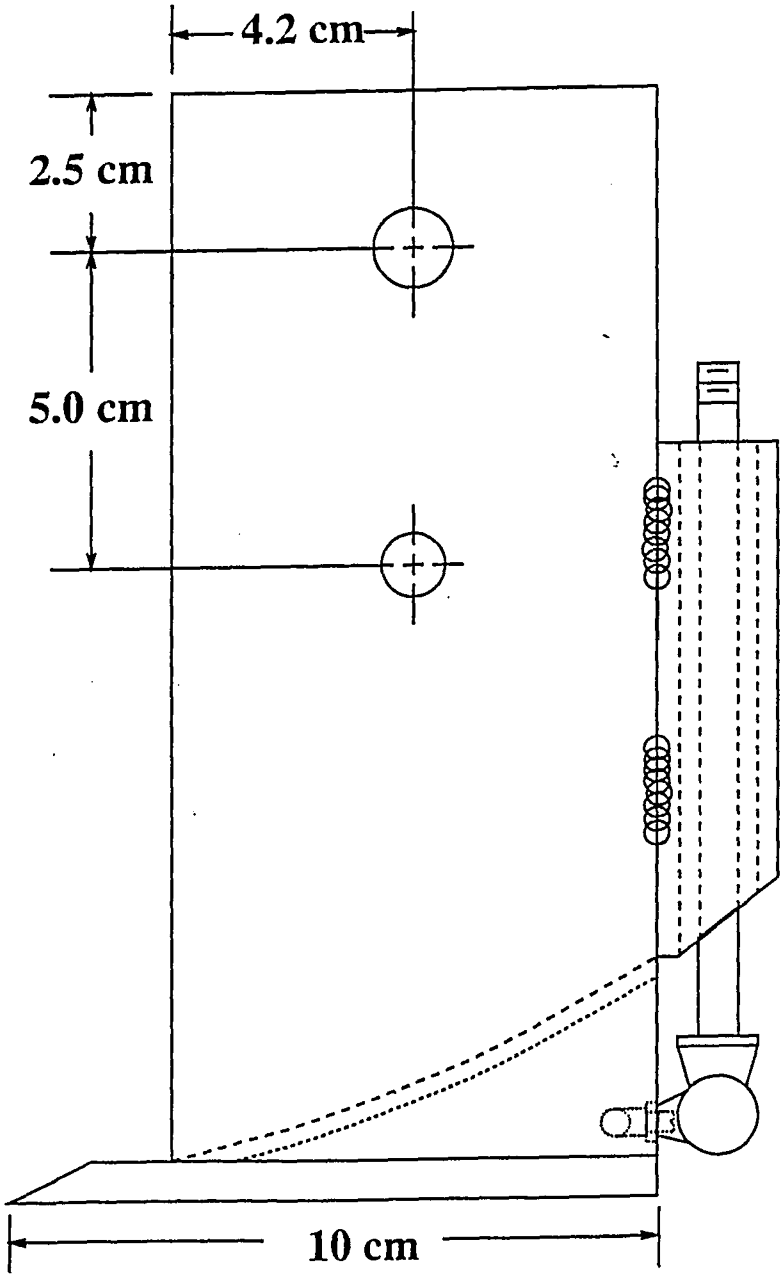

Figure 2.2: Subsurface applicator

applicator appeared to give better weed control than when using the knife injectors. Even so, the injectors were easier to operate, and were more versatile for mounting on various equipment.

Fenster et al. (1962) modified a 2.1-m V-plow for applying liquid herbicides beneath the soil surface. This design allowed for incorporation of volatile herbicides with little plant residue destruction. The 15 cm wide blade lifted the soil 63.5 mm. The soil was then sprayed from underneath using spray nozzles attached to a spray boom located under the v-blade. The advantages of this system were stated to be:

1. established weeds were mechanically destroyed during herbicide application.
2. the herbicide became incorporated without dependence upon rainfall.
3. none of the herbicide was intercepted by the crop residue on the soil surface.
4. the wind did not affect the application.
5. volatile herbicides were incorporated in one operation with minimum loss, and
6. little plant residue was incorporated into the soil.

Disadvantages included depth control, functioning in rocky soil, coverage speed, and additional power requirements.

Barrentine and Wooten (1967) used four different herbicide applicators to evaluate methods of applying preemergent herbicides. The applicators consisted of a 46 cm subsurface spray sweep, a double-five blade reel incorporator, a drop-nozzle surface applicator, and the knife-injector developed by Wooten et al. (1966). This equipment represented subsurface, incorporated, surface, and injected herbicide application methods. All four applicators were attached to a planter used for evaluating the comparative effectiveness of 39 herbicides. The planter-applicator was found to be successful in evaluating the influence of the application methods on the activity of the herbicide applied to the soil.

Another injector-planter was constructed by Dowler and Hauser (1970). Their objectives were to design and construct a herbicide injector-planter that could cut through crop residue and cloddy soil, and could be made from readily available commercial parts. The design used coulters with trailing herbicide injector knives. Once the coulters cut a path for the injector knives, the herbicide could be placed from 2.5 to 10 cm deep. This system functioned better than the previous knife system (Wooten et al, 1966) without the coulters. A floating roller followed the injectors in order to seal and smooth the soil surface.

An applicator similar to Wooten and McWhorter's (1961) horizontal blade applicator was developed by Hollingsworth et al. (1973) for incorporating herbicides into the root zone of saltcedar. Saltcedar is a woody plant found in arid, low rainfall areas. This blade was 2.44 m wide, 55.9 cm broad, and 7.6 cm thick at the trailing edge. The herbicide dripped onto the soil after being sprayed onto the blade's angle iron. The plow could operate to depths of up to 80 cm. Besides applying a uniform layer of herbicide under the soil profile, the plow blade also worked as a cutting device for the saltcedar roots.

Morrison et al. (1980) also devised and evaluated a procedure for incorporating herbicides into the soil profile while maintaining maximum crop residue on the soil surface. They modified a 41-cm wide chisel plow sweep to include a spray nozzle in the back side of the sweep positioned on a horizontal plate. The sweeps were attached on the shanks of a 3-bar chisel plow frame. The sweeps were run from 5 to 10 cm deep for preemergent applications of herbicides for cotton and corn fields. It was concluded that "if surface applied herbicides do not provide adequate weed control, then sweep incorporation should be considered for some conservation tillage cropping systems."

A subsurface jet injector system for herbicides was designed and created by Solie et al. (1983). The purpose of this machine was to incorporate herbicides by jetting them up into the soil passing over sweeping plow blades. The herbicide penetrated the soil while retaining much of the surface residue. Three 1.5 m v-blades with a jet injector manifold were attached to a 4.6 m sweep plow. The plow released the herbicide approximately 8-13 cm deep. Results from using this injector system showed greater weed control, crop stands, and crop yields when compared to both tandem disk incorporation and hand-weeded check treatments. However, this injector required very level soil and had mechanical problems involving the 'flow' of soil and crop residue over the shallow blade.

Using this subsurface injector, Hayden and Burnside (1984) did a comparison with a double tandem disc treatment for controlling forage sorghum in corn. Control was best when the herbicide EPTC was double disced, followed by jet injection where 75 percent was subsurface applied and 25 percent was surface applied. Poor control was noted when the herbicide was 100 percent subsurface applied. Less than 10 percent of the residue was incorporated when using the subsurface injector.

Dawelbeit (1983) designed and tested a residue management implement that allowed incorporation of nutrients and pesticides without incorporation of the surface residue. This system picked the residue up from the soil surface and carried it over the chemical applicator and the tillage-incorporation tool. The residue was then returned to the soil surface. The concept was proven in the field to be feasible. The device was able to pick up a maximum of 63 percent corn residue and tended to improve the distribution of the residue when dropped back on the surface.

CHAPTER 3. DESIGN AND EVALUATION OF A HERBICIDE BAND INJECTION SYSTEM

Introduction

News headlines such as "Researchers find atrazine showing up in rainwater" (Looker, 1990) and the concerns that come with reading such an article, have moved the public and farmers to look for more efficient ways of applying pesticides and nitrogen in order to reduce environmental losses. When used properly, pesticides and fertilizers offer benefits such as increased yields and reduced crop damage.

Herbicides that are applied to the soil for weed control can be grouped according to their need for mechanical incorporation: (1) is effective if left on the soil surface or incorporated, (2) does not provide adequate weed control when incorporated into the soil, or (3) requires mechanical incorporation (Ross and Lembi, 1985). Incorporation has been shown to provide more consistent weed control results when compared to surface applied herbicides over a period of years. Surface applied herbicides typically rely on rainfall to move them into the soil whereas mechanically incorporated herbicide are mixed or placed in the soil by the specific mechanical device. Mechanical incorporation also can reduce losses due to volatilization and photodegradation on the soil surface while at the same time providing better placement of the herbicide for the control of weeds.

An important goal of conservation tillage is to leave as much residue on the surface as possible to prevent soil erosion. Incorporation of herbicides without reducing the surface residue is difficult with the implements used today (Colvin, 1981). This makes it difficult to use herbicides that need mechanical incorporation in order to be effective for weed control or to reduce environmental losses. Several herbicides are more effective when accurately placed within the soil profile. Some herbicide application equipment has been developed to place the herbicides in the soil profile without burying or destroying much of the crop residue.

One of the first devices developed for subsurface application of herbicides was designed and tested by Wooten and McWhorter (1961). This device applied liquid EPTC 5 to 15 cm under the soil profile using a 40 cm wide band of spray approximately 6-mm thick. Soil flowed over a concave blade 50 cm in width. A spray boom was placed inside the angled horizontal blade of the applicator. Adjustable angled spray nozzles applied the herbicide as the blade produced an umbrella of soil under the soil profile. Better control was realized with subsurface application of the herbicide when compared to surface application with rotary hoed incorporation.

Wooten and McWhorter (1962) modified their subsurface herbicide applicator to allow them to apply solid herbicide material such as dust or granules. The spray bar was replaced by a perforated tube or by a single outlet tube. A power-take-off driven duster was used to supply the material to the applicators. Both of the applicators were found to give satisfactory band patterns, although the perforated bar seemed to have a better probability of succeeding.

With the desire to increase the versatility and performance of application beyond that which was found with the horizontal blade applicator, Wooten et al. (1966) came up with a new applicator design. This design, called the Stoneville knife-type herbicide injector, deposited a liquid stream of EPTC in a narrow vertical slot created by each knife injector. The injectors were spaced 5 cm apart, with two knives placed in each side of a planting drill. When the spacing of the injectors was greater than 6.4 cm apart, weed control was dramatically decreased. The older horizontal blade applicator appeared to give better weed control than when using the knife injectors. Even so, the injectors were easier to operate, and were more versatile for mounting on various equipment.

Fenster et al. (1962) modified a 2.1-m V-plow for applying liquid herbicides beneath the soil surface. This design allowed for incorporation of volatile herbicides with little plant residue destruction. The 15-cm wide blade lifted the soil 6.4 cm. The soil was then sprayed from underneath using spray nozzles attached to a spray boom located under the v-blade. The advantages of this system were stated to be:

1. established weeds were mechanically destroyed during herbicide application.
2. the herbicide became incorporated without dependence upon rainfall.
3. none of the herbicide was intercepted by the crop residue on the soil surface.
4. the wind did not affect the application.
5. volatile herbicides were incorporated in one operation with minimum loss, and
6. little plant residue was incorporated into the soil.

Disadvantages included depth control, functioning in rocky soil, coverage speed, and additional power requirements.

Barrentine and Wooten (1968) used four different herbicide applicators to evaluate methods of applying preemergent herbicides. The applicators consisted of a

46 cm subsurface spray sweep, a double-five blade reel incorporator, a drop-nozzle surface applicator, and the knife-injector developed by Wooten et al. (1966). This equipment represented subsurface, incorporated, surface, and injected herbicide application methods. All four applicators were attached to a planter used for evaluating the comparative effectiveness of 39 herbicides. The planter-applicator was found to be successful in evaluating the infuence of the application methods on the activity of the herbicide applied to the soil.

An applicator similar to Wooten and McWhorter's (1961) horizontal blade applicator was developed by Hollingsworth et al. (1973) for incorporating herbicides into the root zone of saltcedar. Saltcedar is a woody plant found in arid, low rainfall areas. This blade was 2.44 m wide, 55.9 cm broad, and 7.6 cm thick at the trailing edge. The herbicide dripped onto the soil after being sprayed onto the blades angle iron. The plow could operate to depths of up to 80 cm. Besides applying a uniform layer of herbicide under the soil profile, the plow blade also worked as a cutting device for the saltcedar roots.

Morrison et al. (1980) also devised and evaluated a procedure for incorporating herbicides into the soil profile while maintaining maximum crop residue on the soil surface. They modified a 41-cm wide chisel plow sweep to include a spray nozzle in the back side of the sweep positioned on a horizontal plate. The sweeps were attached on the shanks of a 3-bar chisel plow frame. The sweeps were run from 5 to 10 cm deep for preemergent applications of herbicides for cotton and corn fields. It was concluded that "if surface applied herbicides do not provide adequate weed control, then sweep incorporation should be considered for some conservation tillage cropping systems."

A subsurface jet injector system for herbicides was designed and created by Solie et al. (1983). The purpose of this machine was to incorporate herbicides by jetting them up into the soil passing over sweeping plow blades. The herbicide penetrated the soil while retaining much of the surface residue. Three 1.5 m v-blades with a jet injector manifold were attached to a 4.6 m sweep plow. The plow released the herbicide approximately 8-13 cm deep. Results from using this injector system showed greater weed control, crop stands, and crop yields when compared to both tandem disk incorporation and hand-weeded check treatments. However, this injector required very level soil and had mechanical problems involving the 'flow' of soil and crop residue over the shallow blade.

Using this subsurface injector, Hayden and Burnside (1984) did a comparison with a double tandem disc treatment for controlling forage sorghum in corn. Control was best when the herbicide EPTC was double disced, followed by jet injection where 75 percent was subsurface applied and 25 percent was surface applied. Poor control was noted when the herbicide was 100 percent subsurface applied. Less than 10 percent of the residue was incorporated when using the subsurface injector.

Dawelbeit (1983) designed and tested a residue management implement that allowed incorporation of nutrients and pesticides without incorporation of the surface residue. This system picked the residue up from the soil surface and carried it over the chemical applicator and the tillage-incorporation tool. The residue was then returned to the soil surface. The concept was proven in the field to be feasible. The device was able to pick up a maximum of 63 percent corn residue and tended to improve the distribution of the residue when dropped back on the surface.

The objectives for the portion of the study reported here were two fold:

1. To develop and implement the design for a point injection system that could:

   (a) inject herbicides in the soil profile at a desired position without spraying,

   (b) incorporate the herbicide in a single pass through the field, and

   (c) leave the residue on the soil surface (with conservation tillage) virtually undisturbed.

2. To evaluate the use of this point injection system on weed control under field conditions.

Materials and Methods

Design and Construction

The concept design for applying herbicides with some type of point injection system is patterned after the point-injector fertilizer applicator developed at Iowa State University (Baker et al., 1989). This fertilizer applicator injects liquid fertilizer about 10 cm below the soil surface using a single wheel of 12 points spaced 20 cm apart at the tips. The advantages of this injector wheel "included fertilizer incorporation with low power requirements, minimum soil and residue disturbance, and additional timing and placement options for efficient fertilizer management."

In the initial phase of this project, an 'applicator cylinder' for injecting pesticides (in a liquid form) into the soil was design and constructed. This spoked wheel is similar to the point-injector fertilizer applicator (Baker et al., 1989), but with many more rows of spokes. The point-injector cylinder (PIC) was designed for band application of preemergent pesticides. Figure 3.1 shows the first configuration designed and fabricated for field testing. The second generation point-injection cylinder is shown in Figure 3.2.

Both of these designs are made of an 17.8 cm high-density polyethylene rod, with a 3.8 cm brass axle. These materials have been chosen for their noncorrosive and low absorption characteristics. The points for injecting the pesticide are made of 0.48 cm brass rod. Design one (Figure 3.1) has a total of 44 points in four rows that cover a 20 cm band, with each point designed to have an effective radius of influence of 2.5 cm. The second design (Figure 3.2) has 176 points, with each point having an effective radius of 1.3 cm. The points extend 3.3 cm beyond the polyethylene rod with a 1.6 mm hole drilled to within 7.6 mm of the tip. At this point a 1.5 mm hole is drilled perpendicular to the bored hole to effectively inject the pesticide 2.5 cm below the soil surface (Figure 3.3). This depth has previously been found to be the optimum depth of soil incorporation for many of the common soil incorporated herbicides, such as: EPTC, trifluralin, atrazine, propachlor, and chloramben (Knake et al., 1967).

The hole for the injection was determined to be the most effective size in order to decrease the probability of plugging. This was determined using various size holes in field tests. The L-shaped channel in the points reduces the soil pressure exerted at the hole, therefore decreasing the chances for plugging.

The axle has a manifold on each side of the wheel that splits the liquid to each row of points (Figure 3.4). The axle is fed with liquid on each end through polyethylene tubing at pressures ranging from 140 to 551 kPa (higher pressures are possible). The points are offset so that only one point is injecting at a time. This way each point can effectively inject an equal volume of liquid. Injection takes place

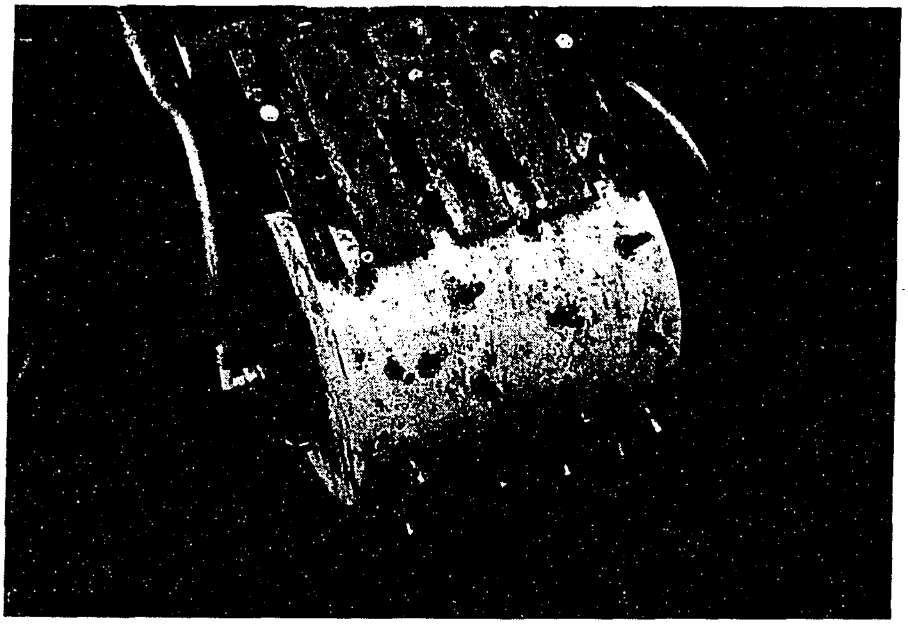

Figure 3.1: Point-injector cylinder with 5 cm point spacing

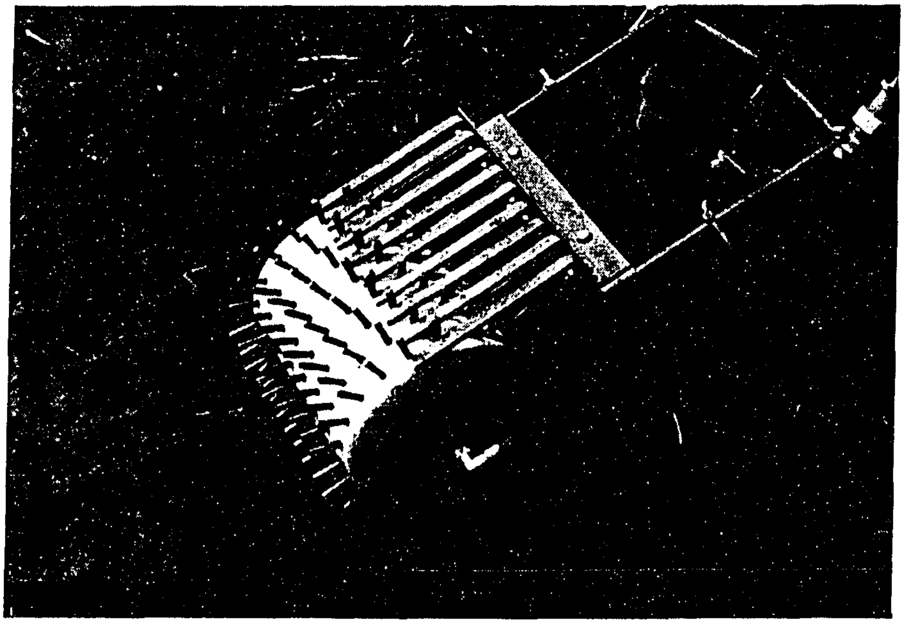

Figure 3.2: Point-injector cylinder with 2.5 cm point spacing

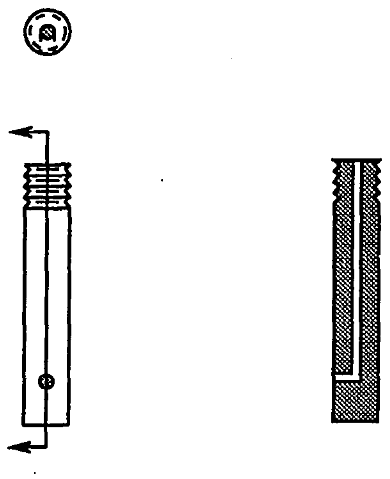

Figure 3.3: Injection point

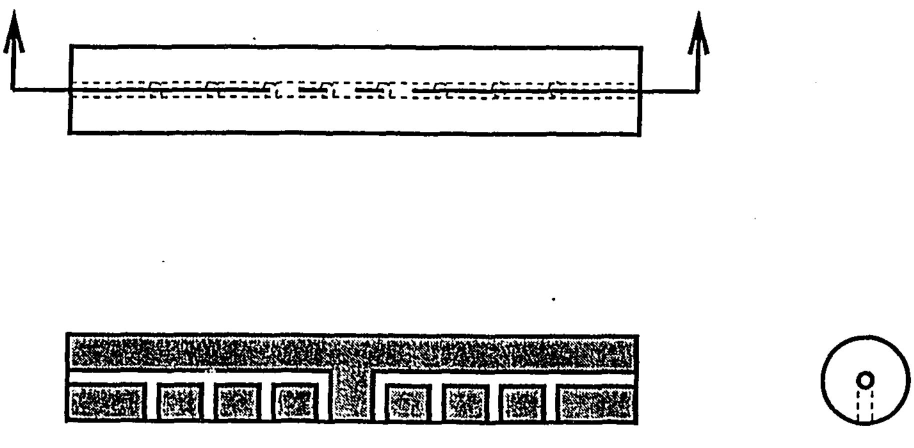

Figure 3.4: Point-injector axle

when the points are in alignment with the manifold opening in a down position. The scrapers shown in Figure 3.1 and Figure 3.2 are made of 4.8 mm flat steel, and are attached to keep residue, clods, rocks, and other debris from interfering with the function of the injector.

A third design varies every other point length in order to distribute the herbicides better within the soil profile. This design uses 2.5 cm and 1.3 cm point lengths (Figure 3.5). O-rings were also added 3 cm from each end of the axle to decrease the possibility of liquid pesticide escaping at the ends of the cylinder. The rest of the features are the same as the second design. A design with varying 2.5 cm and 5 cm point lengths was tested in the field, but point breakage occurred at the cylinder surface. Thicker point walls or stronger point material could make this design function better in the future.

During the summer of 1991 four new PICs were constructed using 2.5 cm stainless steel points. These points were made from 6.35 mm hollow stainless steel rod with a 2.4 mm hole. The one end was spot welded and ground to a point, and the other end was threaded to mate with the polyethylene cylinder. Brackets were designed and manufactured to mount this new generation PIC to a five row planter for field testing. The total set up of this fourth generation PIC is shown in Figure 3.6.

Due to the labor involved with manufacturing the points, several design modifications have been considered. One version uses a tight fit screw for plugging one end of the hollow tubing, and leaves off the threading on the other end. The points would then be force fit into the polyethylene rod. This would allow more of the manufacturing to be done on a NC-lathe, thus saving time and money.

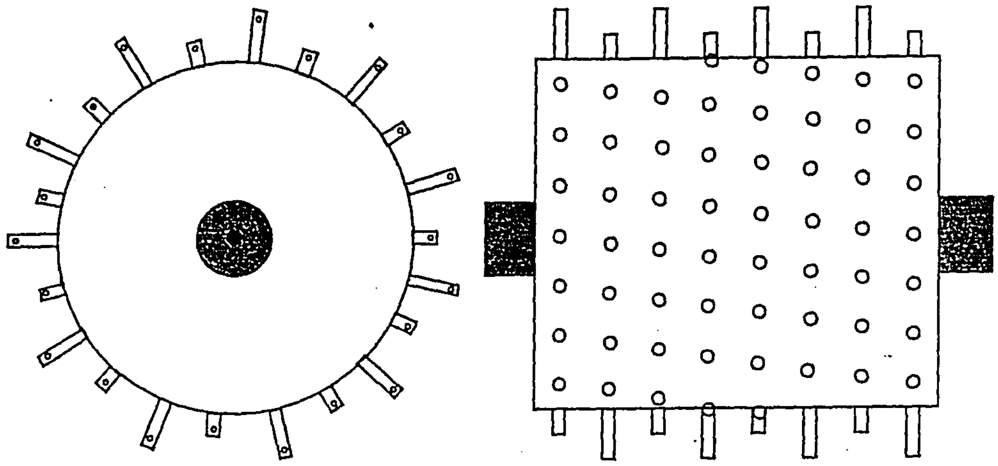

Figure 3.5: Varying point length design

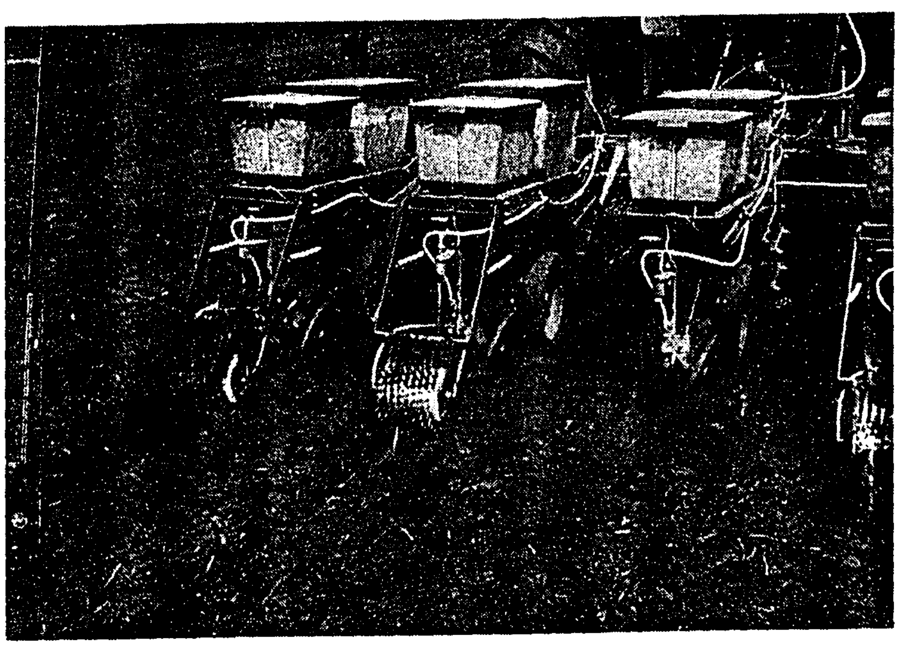

Figure 3.6: Fourth generation design attached to a planter

Growth Chamber Study

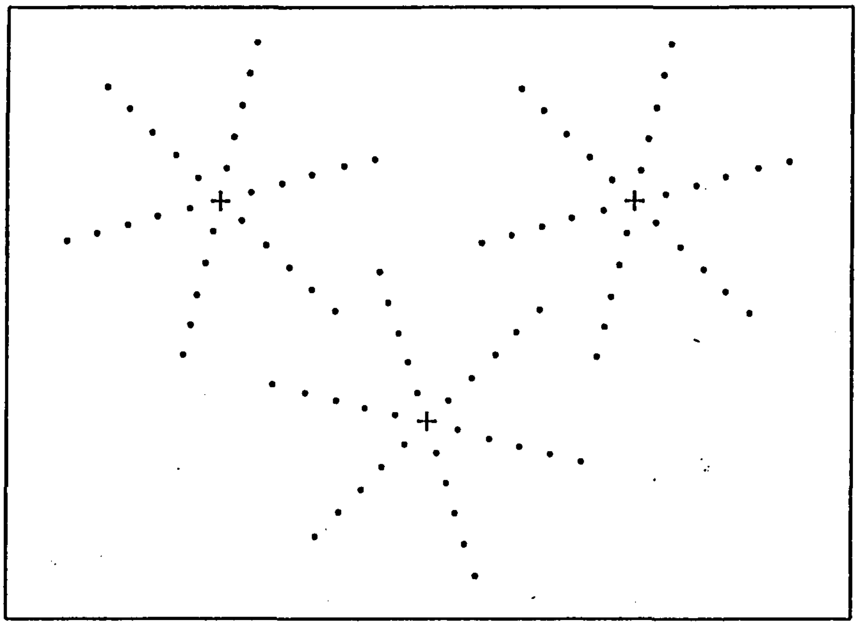

Figure 3.7: Growth chamber star pattern, (+ indicates injection location)

During the design and construction period of the injector, a growth chamber study was conducted to determine the area of influence of liquid cyanazine and alachlor when injected at a point in the soil. Giant foxtail was used as a test species, since it was susceptible to both herbicides and had a high germination rate. Seeds were planted using an 1 cm spacing along the rays of a 6-pointed star with the herbicide injection at the center (Erbach, 1976a). Three such stars were placed in a plastic pan 26.5 cm long, 19 cm wide, and 9 cm deep (Figure 3.7). Two seeds were planted at each position on the star to increase the chance of a seed germinating at a a given position.

Each pan had a cyanazine and an alachlor injection star, plus a star with no herbicide injection as a check. The seeds were planted in soil that had been sieved and that had the moisture content raised to approximately 20 percent by stirring in water that had been added with a hand sprinkler. The seeds were planted at 1 and 2 cm depths, and the injections volumes used were 187 L/ha and 748 L/ha. The herbicides were all injected 2.5 cm below the soil surface. The rates used for alachlor and cyanazine was 2.2 kg/ha. Each treatment was replicated four times. After planting, the pans were watered regularly every 3 to 4 day with approximately 1.2 cm of water.

Control was determined visually 28 days after planting. Various rating were given that related to the amount of control for the herbicides. The ratings were 0, 2.5, 5, 7.5, or 10. A rating of 10 was considered complete control, and a rating of a 0 was related to no control (Erbach, 1976a).

Effectiveness Studies - 1989

Work was performed in the summer of 1989 to develop preliminary information on the effect of herbicide injection in points on weed control. This initial study used atrazine, alachlor, propachlor, butylate, and EPTC on oats as a test species. The application rate for each of these herbicides was 2.2, 2.2, 2.2, 3.4, and 0.56 kg/ha, respectively. The field area was disked twice prior to planting and herbicide application. The field had previously been planted to corn. Webster oats were used as the test species, and were planted using a grain drill. The herbicides were all applied immediately after the oats were planted. Treatments included broadcast spray followed by disc incorporation, and band injection. A treatment with no herbicide applied was also included as a check. Four replications were made for each herbicide/treatment combination, requiring a total of 44 plots. The plots were laid out using a completely randomized design. The PIC used was design 1 (Figure 3.1), with the 5 cm point spacing. The PIC was pulled behind a tractor, attached to a spring loaded bracket system. The bracket system included set of pillow blocks that attached to each side of the axle to hold it in position. Oat counts within a 20 cm x 60 cm area were made in three positions within each plot 7, 14, and 21 days after planting and herbicide application.

The results from this effectiveness study and the growth chamber study showed that the point spacing would have to be closer for the point injector to be more effective. Using the re-designed point-injection cylinder shown in Figure 3.2 with 176 spokes, a similar study was conducted (the 'sphere of influence' of each point had to have a radius of 1.3 cm to provide control over the total 20 cm banded area). Herbicides were either applied with a broadcast sprayer, followed by a disk, or the PIC to areas planted to a test species of Webster blend oats. The oats were planted with a broadcast oat seeder after field cultivation and then followed by a culti-packer. Observations were made as to the relative control of the oats using the herbicides atrazine, EPTC, butylate, and trifluralin. The application rates applied were 2.2, 2.2, 3.4, and 0.56 kg/ha respectively. A spray or injection volume of 187 L/ha was used. A check treatment was also included for comparison. Four replications of each treatment were set up. The herbicides were tested individually to detect differences in spheres-of-influence, if any. Three 20 cm x 60 cm areas were set up within each plot for counting the oat population. Oat counts were made 11, 17, and 29 days after emergence.

Effectiveness Study - 1990

A similar effectiveness study was conducted in the field the following year (summer of 1990). This time two different PIC designs were used to apply the herbicides. The 176-point-injection cylinder with the uniform 2.5 cm injection depth was used with trifluralin, butylate, and EPTC. The other PIC used also had 176 points, but the points alternated from a 2.5 cm injection depth to a 1.3 cm injection depth. The new design was used with atrazine and alachlor. Each cylinder was attached to a spring loaded cultivator sweep, that was attached to a 3-point hitch bar. Higher rates were used for most of the herbicides, and the spray or injection volume was increased to 561 L/ha. The increased volume was to help insure little or no plugging of the injection points. Application rates for atrazine, EPTC, butylate, and trifluralin were 3, 3, 1.25 and 0.5 kg/ha respectively. With the exception of not culti-packing the oats, the rest of the procedures were the same as the year before.

Effectiveness Study - 1991

In the spring of 1991, a 2.5-ha field was planted to corn using a five row John Deere planter with the fourth generation PICs attached to it. Every other set of five rows were either band sprayed or band injected with alachlor and cyanazine behind the planter. A PIC was left off of the center row of the planter to represent a check treatment. Eight passes, 390 meters in length, were made with the PICs and the band sprayers. Approximately 2.2 kg/ha and 2.9 kg/ha of each herbicide were applied to the band sprayed and band injected treatments, respectively. The difference was due to the higher line pressures required to insure no point plugging because of the high moisture content of the soil, and was not intentional. An injection volume of 842 L/ha was applied using line pressure of 410 kPa for 5 passes. The tractor and planter were moving at a velocity of 9.6 km/h. Two other injection passes using a line pressure of 210 kPa and a tractor speed of 6.4 km/h were made; thus the injection volume was 910 L/ha. The other pass was made using a line pressure of 280 kPa and a tractor speed of 8 km/h, with an injection volume of 690 L/ha. The field was treated with the nonselective herbicide glyphosate with crop oil before planting. Weed counts were made 25 days after planting. Six weed counts in an area of 20 cm x 60 cm were made for each corn row. Typical weeds inclued foxtail, pigweed, and velvetleaf.

Results and Discussion

Tables 3.1 and 3.2 show the results from the growth chamber study. Table 3.1 shows the effect of seed depth placement on the control of giant foxtail when injecting the herbicides cyanazine and alachlor 2.5 cm below the soil surface. Control is significant (at the 5 percent level) when comparing cyanazine to the check treatment, 1 cm from the point of herbicide injection. Control is also significantly higher for cyanazine when injected closer to the weed seed. This is also the case for alachlor, although not at a significant level. No adequate control is found for either herbicide much beyond the 1 cm distance from the point of injection. Better control could be expected with cyanazine, since it is mainly absorbed through the roots. Alachlor is absorbed mainly through the shoots of the weed plants. Since the injections were always below the planted seeds, lower control could be expected when using alachlor.

In Table 3.2, the effect of using two different injection volumes on the control of the giant foxtail is shown. In general, cyanazine is effective in controlling the foxtail using either the 187 or the 748 L/ha injection volume, 1 cm from the point of

Table 3.1: Effect of seed depth on control of giant foxtail using cyanazine and alachlor[a]

Horizontal Distance from point of injection[b] (cm)	Check Treatment[c]	Cyanazine Treatment Seed Depth 1 cm	Cyanazine Treatment Seed Depth 2 cm	Alachlor Treatment Seed Depth 1 cm	Alachlor Treatment Seed Depth 2 cm	LSD, 5 %
1	5.2	6.6	8.0	5.8	6.4	1.3
2	3.6	4.7	4.6	4.1	4.9	1.5
3	3.0	3.5	4.3	3.6	2.8	1.4
4	3.2	1.9	3.2	2.6	3.8	1.3
5	2.1	2.5	2.2	2.0	3.0	1.3
LSD, 5 %	1.8	1.8	1.8	1.8	1.8	

[a]0 = no control 10 = complete control.
[b]Injection depth = 2.5 cm.
[c]No herbicide injection.

Table 3.2: Effect of injection volume on control of giant foxtail using cyanazine and alachlor[a]

Horizontal Distance from point of injection[b] (cm)	Check Treatment[c]	Cyanazine Treatment Injection Volume, L/ha 187	Cyanazine Treatment Injection Volume, L/ha 748	Alachlor Treatment Injection Volume, L/ha 187	Alachlor Treatment Injection Volume, L/ha 748	LSD, 5%
1	5.2	6.8	7.8	6.6	5.6	1.4
2	3.6	4.2	5.2	4.9	4.1	1.5
3	3.0	4.0	3.8	3.4	3.0	1.4
4	3.2	2.6	2.6	3.5	2.9	1.4
5	2.1	2.2	2.5	2.5	2.6	1.3
LSD, 5%	1.8	1.8	1.8	1.8	1.8	

[a]0 = no control 10 = complete control.
[b]Injection depth = 2.5 cm.
[c]No herbicide injection.

injection. Even though there is no significant difference between between injection volume control, better control is apparent up to 2 cm from the injection point with the higher injection volume. No significant control is noticeable at either injection volume for alachlor. This again is probably due to the placement of the injection in relationship to the seed depth.

Results from this growth chamber study revealed that the spoke spacing for the injector would have to be closer, than that for the first point-injector constructed (Figure 3.1), for adequate coverage of the herbicides in the soil profile. The second point-injector (Figure 3.2) was therefore designed with an effective radius of influence of 1.3 cm for each point. It was also decided to shorten the point injection depth on the cylinder for herbicides like alachlor, which are more effective if applied at or above the weed seed. This would increase the chances of the weed shoots passing through the herbicide zone. These changes were incorporated into the third point injector cylinder design (Figure 3.5). This varying point length design used both 1.3 and 2.5 cm point lengths.

Tables 3.3, 3.4, and 3.5 give the average oat counts for the application method and herbicide combinations. The oats counts are shown for 7, 14 and 21 days after planting and herbicide application. Seven days after herbicide application (Table 3.3), the herbicides propachlor, EPTC, butylate, and trifluralin were already starting to effectively control the oats when disk incorporated. Only butylate showed any significant difference from the check count, for the band injected herbicides. By the fourteenth day after application (Table 3.4), all the disk incorporated herbicides were showing adequate control. Atrazine, butylate, and trifluralin also showed significant control when band injected, but were significantly worse than the disked treatments.

Table 3.3: Herbicide application effectiveness when controlling oats in a field setting (7 days after planting), 5 cm point spacing, 1989

Application Method	Oat count[a] for herbicide -				
	Atrazine	Butylate	EPTC	Propachlor	Trifluralin
Band Injected	34	28	33	38	34
Sprayed/Disked	32	4	2	29	16
Check	37	37	37	37	37
LSD, 5%	7	7	7	7	7

[a]Average oat count for 20-cm X 60-cm areas.

The final count (Table 3.5) shows that for all the herbicides, except propachlor, the disk incorporated treatments performed significantly better that the band injected treatments. Yet, atrazine, EPTC, and butylate did show significant differences when band injected as compared to the check treatment.

Although some effectiveness was found using the 5 cm point spacing, it was not as good as had been hoped for. These results corresponded with the findings from the growth chamber study. It was at this time that a new design with a closer point spacing was created.

During the next effectiveness study, when using the second design with 2.5 cm point spacing, it was discovered that the injector showed some effectiveness in controlling the oats only when using butylate and EPTC. Little or no control was detected with trifluralin or atrazine. Oat counts within the 20 cm x 60 cm areas were made 17, 24, and 34 days after planting. Oat counts were taken later than that in the first study because of the dry soil conditions causing later germination of the oats.

Table 3.4: Herbicide application effectiveness when controlling oats in a field setting (14 days after planting), 5 cm point spacing, 1989

Application Method	Oat count[a] for herbicide -				
	Atrazine	Butylate	EPTC	Propachlor	Trifluralin
Band Injected	19	17	23	26	22
Sprayed/Disked	4	2	0.5	20	4
Check	28	28	28	28	28
LSD, 5%	6	6	6	6	6

[a]Average oat count for 20-cm X 60-cm areas.

Tables 3.6, 3.7, 3.8 show the average oats counts for the two application methods and the four herbicides applied. Atrazine, butylate, and EPTC for both application methods showed significantly lower oats counts in the rectangular test area when compared to the check areas. Trifluralin was found to be ineffective in controlling the oats when band injected, but was effective when sprayed and incorporated. Although the oat count for the sprayed/disked atrazine areas was high 17 days after planting, the count changed drastically by day 24. Within 24 days after planting, the sprayed/disked plot all had better control in comparison to the injected areas. Even so, there was no significant difference between the application methods on the oat control when using EPTC , atrazine, or butylate. EPTC by far, gave the best control for both application methods. By day 34 after planting, no change in control from the previous count was noticeable for any of the herbicides and application methods.

It was determined that back-pressure at the injector points was causing smaller volumes of the herbicides to be applied. Less than the desired application rate was

Table 3.5: Herbicide application effectiveness when controlling oats in a field setting (21 days after planting), 5 cm point spacing, 1989

Application Method	Oat count[a] for herbicide -				
	Atrazine	Butylate	EPTC	Propachlor	Trifluralin
Band Injected	14	11	15	16	17
Sprayed/Disked	0.5	1	0	12	1
Check	22	22	22	22	22
LSD, 5%	7	7	7	7	7

[a]Average oat count for 20-cm X 60-cm areas.

Table 3.6: Herbicide application effectiveness when controlling oats in a field setting (17 days after planting), 1989

Application Method	Oat count[a] for herbicide -			
	Atrazine	Butylate	EPTC	Trifluralin
Band Injected	57	31	20	69
Sprayed/Disked	63	13	1	29
Check	77	77	77	77
LSD, 5%	20	20	20	20

[a]Average oat count for 20-cm X 60-cm areas.

Table 3.7: Herbicide application effectiveness when controlling oats in a field setting (24 days after planting), 1989

Application Method	Oat count[a] for herbicide -			
	Atrazine	Butylate	EPTC	Trifluralin
Band Injected	52	39	17	69
Sprayed/Disked	36	12	0	25
Check	74	74	74	74
LSD, 5%	19	19	19	19

[a]Average oat count for 20-cm X 60-cm areas.

actually being applied in some cases, depending on the soil conditions. This problem was corrected and the study was run again the following year (1990).

The effectiveness study of 1990 was run as a completely randomized field study. Five herbicides were used; alachlor, atrazine, butylate, EPTC, and trifluralin. The application methods were band injection and broadcast spraying with disk incorporation. The average oat counts for 20 cm x 60 cm areas within the plots, two weeks and three weeks after planting and herbicide application, are given in Table 3.9 and Table 3.10, respectively.

No significant difference was found between the application methods for the herbicides atrazine, alachlor, butylate, and EPTC. This indicates that the band injector was equally effective in controlling the oats species when compared to the sprayed/disked treatment. For trifluralin, the sprayed/disked treatment was significantly more effective in controlling the oats. This could be due to the fact that trifluralin has a high adsorption coefficient, and is not highly mobile in the soil once

Table 3.8: Herbicide application effectiveness when controlling oats in a field setting (34 days after planting), 1989

Application Method	Oat count[a] for herbicide -			
	Atrazine	Butylate	EPTC	Trifluralin
Band Injected	56	38	16	68
Sprayed/Disked	40	15	0	22
Check	74	74	74	74
LSD, 5%	18	18	18	18

[a]Average oat count for 20-cm X 60-cm areas.

Table 3.9: Herbicide application effectiveness when controlling oats in a field setting (14 days after planting), 1990

Application Method	Oat count[a] for herbicide -				
	Atrazine	EPTC	Alachlor	Butylate	Trifluralin
Band Injected	19	5	17	19	23
Sprayed/Disked	32	5	16	24	14
Check	41	41	41	41	41
LSD, 5%	11	11	11	11	11

[a]Average oat count for 20-cm X 60-cm areas.

Table 3.10: Herbicide application effectiveness when controlling oats in a field setting (21 days after planting), 1990

Application Method	Oat count[a] for herbicide -				
	Atrazine	EPTC	Alachlor	Butylate	Trifluralin
Band Injected	43	7	47	46	45
Sprayed/Disked	45	8	44	56	24
Check	72	72	72	72	72
LSD, 5%	18	18	18	18	18

[a] Average oat count for 20-cm X 60-cm areas.

incorporated. Since the point injector places the herbicide at a point, the trifluralin was not distributed uniformly within the soil profile enough to be as effective. Disking would distribute the herbicide more uniformly in the soil profile. EPTC had significantly better control for both application method when compared to the other herbicide treatments.

It should be noted that design 2 (Figure 3.1) was used with the herbicides: butylate, EPTC, and trifluralin. Design 3 (Figure 3.2), with the variable point lengths, was used with atrazine and alachlor.

Atrazine showed better control 14 days after planting for the band injected plot, but seven days later no significant difference was found between the band injected plots and the sprayed/disked plots. Shallow incorporation of atrazine and alachlor by the varied point length injector design was effective in controlling the oats. No comparison was made against the uniform 2.5 cm point length design to see if there would be a large difference in control, although this could be done in future studies.

Table 3.11 shows the results from the 1991 weed control effectiveness study. In this field study the injector wheels functioned very well, even in wet soil. The wheel worked best on the ridge when the top of the ridge was not disturbed, and the surface was dry. Soybean residue from the previous year's crop, caused no problems for the injector. The wheels did ball up with mud when passing through a wet mud hole that had just been field cultivated. This caused plugging of the points.

Table 3.11: Herbicide application effectiveness when controlling weeds in a field setting(24 days after planting), 1991

Application Method	Weed count[a] for herbicides - Alachlor & Cyanazine
Band Injected	0.2
Band Sprayed	0.6
Check	8.7
LSD, 5%	1.4

[a]Average weed count for 20-cm X 60-cm areas.

Although different application volumes and line pressures were used in the 1991 study with the PIC, approximately 2.9 kg/ha of alachlor and cyanazine was applied on all the plots. The band sprayed plots had approximately 2.2 kg/ha of alachlor and cyanazine applied. The differences in application rate were not intentional. No significant difference was found between the two band application methods. Both methods gave good weed control within the banded area. Slightly better control can be seen with the band injector, but this could be due to the slightly higher application rate of alachlor and cyanazine.

Even though alachlor did not do well in the growth chamber study, it did seem to do a good job of weed control in this study. This could be due to the fact that as the wheels turned behind the planter, some of the liquid in the points was thrown out of the points and onto the soil surface within the band. This would make it possible for the weed shoots to grow through or come into contact with the alachlor.

Conclusions

1. A band injection cylinder has successfully been designed and constructed for applying liquid herbicides into the the soil profile up to 2.5 cm in depth. This system mechanically functions well at line pressures ranging from 140 to 410 kPa at speeds up to 9.6 km/h.

2. A band injection system can incorporate herbicides in a single pass through the field while leaving the soil surface virtually undisturbed. The injector functioned effectively on both bare soil surfaces and soil covered with corn residue.

3. Using results from a growth chamber study and field effectiveness studies, a point spacing of 2.5 cm was determined to be better than a 5 cm spacing for the injector. Point spacings of 5 cm was found to be inadequate for the herbicides used.

4. No significant difference was found between band injection and band spraying methods in controlling oats for the herbicides atrazine, alachlor, butylate, and EPTC. Weed control was significantly higher for trifluralin when disk incorporated versus injected.

5. Band injection using alachlor and cyanazine adequately controlled weeds in the band when applied behind a planter in a field study. No significant difference was found between the weed control for band injection vs. band spraying.

CHAPTER 4. PERSISTENCE OF HERBICIDES WHEN BAND INJECTED INTO THE SOIL PROFILE

Introduction

When a herbicide is applied to a field it is important to know how long it will remain in the soil. This is known as its persistence. The persistence of a herbicide is of great importance when considering environmental issues. For example, herbicides that are water soluble, not strongly held to soil particles, and have a long persistence are more likely to leach into the groundwater. Carsel and Smith (1987) define a persistent compound as one that does not hydrolyze or biodegrade readily, has a low vapor pressure, has a high adsorption coefficient, and has a low potential to leach to the groundwater. A nonpersistent pesticide is defined as one that hydrolyzes or biodegrades readily, has a high vapor pressure, is highly water soluble, has a low adsorption coefficient, and has a high potential to move to the groundwater.

Persistence is typically quantified in terms of the amount of time it take one-half the the initial herbicide to disappear. This is known as the herbicide's half-life. Herbicides with long half-lives may carryover and cause damage to the next crop, while those whose half-lives are very short may not persist long enough to provide the necessary weed control (Koskinen and Harper, 1984).

Variations in persistence are attributed to such factors as: herbicide application rate and formulation, soil type, soil-water content, temperature, soil pH, soil clay content and organic matter, and other factors (Ogle and Warren, 1954). These factors determine how much photochemical, microbiological, and chemical transformation of herbicides takes place in soil. Photolysis or photodegradation typically takes place in the top millimeter of soil (Herbert, 1987), microbial degradation is a major factor in the root zone, and chemical decomposition can take place throughout (i.e. the root zone, the vadose zone, and the saturated zone or aquifier).

Conditions that increase the soil microbial activity will increase the herbicide degradation, thus decreasing the persistence of a herbicide. These conditions include increased pH, soil-water content, soil temperature, and organic matter content (Soil Conservation Service, 1983). In a study of the behavior of atrazine and cyanazine in soil with varying pH levels, Blumhurst (1989) found that the degradation of cyanazine decreased as the soil pH decreased. Microbial degradation was the major contributing factor in neutral to slightly basic soils, while chemical degradation was greater in a low pH soil. Walker (1974, 1976, 1978, 1987) developed a computer program for modeling the persistence of herbicides in the soil. His model combines the effects of soil temperature and soil moisture content on the rates of herbicide loss. The input variables include maximum and minimum air temperature and rainfall from available weather data. Walker (1976) evaluated the effect of soil temperature and soil moisture content on the persistence of the herbicides simazine and prometryn. The half-lives for both herbicides decreased as the soil moisture increased. The rate of degradation also increased as the initial herbicide concentration decreased and as the temperature increased.

In the previous chapter, an injection system designed for band application of preemergent herbicides was described. This injection system could effectively apply herbicides 1 to 3 cm beneath bare and residue covered soil surfaces. To be a viable design it was important to determine how point injection would effect the persistence of herbicides with varying properties. The objectives of this study were to evaluate this point injection system on herbicide persistence in the soil with both bare and residue covered soil surfaces, and to model this persistence through the 21 day sampling period.

Materials and Methods

Application Methods

Work was done during the spring of 1989 to evaluate the relative persistence of banded herbicides, either sprayed on a bare soil surface or applied with the point injector cylinder (PIC) shown in Figure 4.1. Both the band sprayer and the PIC were attached to a bar on a spray tank system (Figure 4.2). This point injection system was discussed in detail in the previous section. This design was made expecting a 2.5 cm effective radius of influence for each of the 44 injection points to apply the herbicides in a 20 cm band. It was expected that injection would decrease herbicide volatilization and photodegradation and thus increase persistence. The bare soil surface represented either chisel plow (plow-disk-plant) tillage or strip-tillage (e.g., Buffalo till-plant on ridges). In addition, a flat no-till surface with crop residue on it was also used to test the difference in persistence between the application methods and tillage.

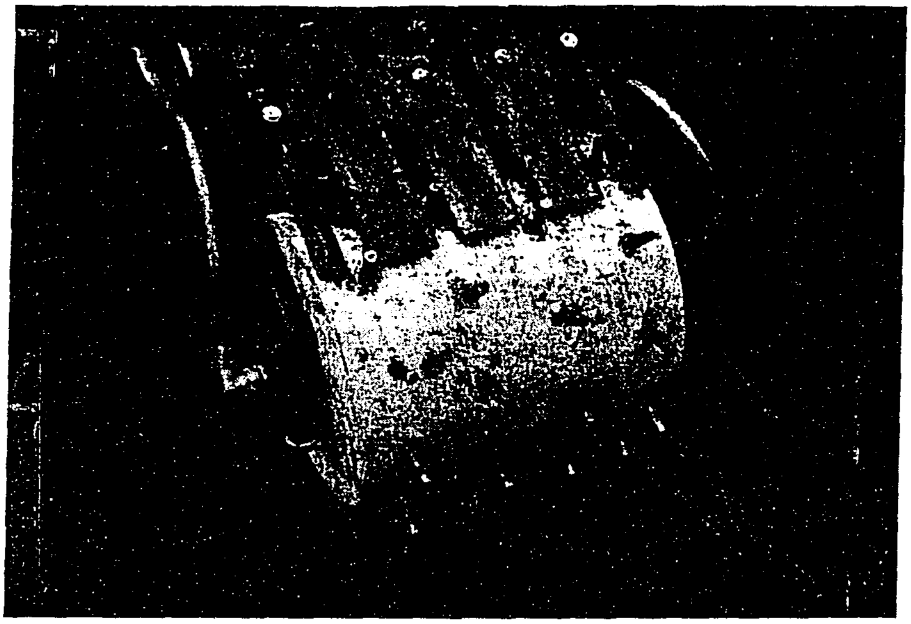

Figure 4.1: Point-injector cylinder with 5 cm point spacing

Plot Set-up

Corn residue was used since the applicator wheel functioned well through it. The percentage crop residue cover was measured by using the photo grid method of Laflen et al. (1981). The residue was taken from a stack of corn stalks taken from a field from the previous years crop and hand distributed on the field. The average residue cover before application of herbicides was 79 percent. Laboratory tests showed that no detectable levels of herbicides in the corn residue. Poultry netting was used to hold the corn residue in place, before and after herbicide application, so that little was moved or lost due to wind. Differences in application amounts deposited between spraying and injection were measured by soil sampling immediately after application. Filter papers, four thick, were placed on the surface of the sprayed plots

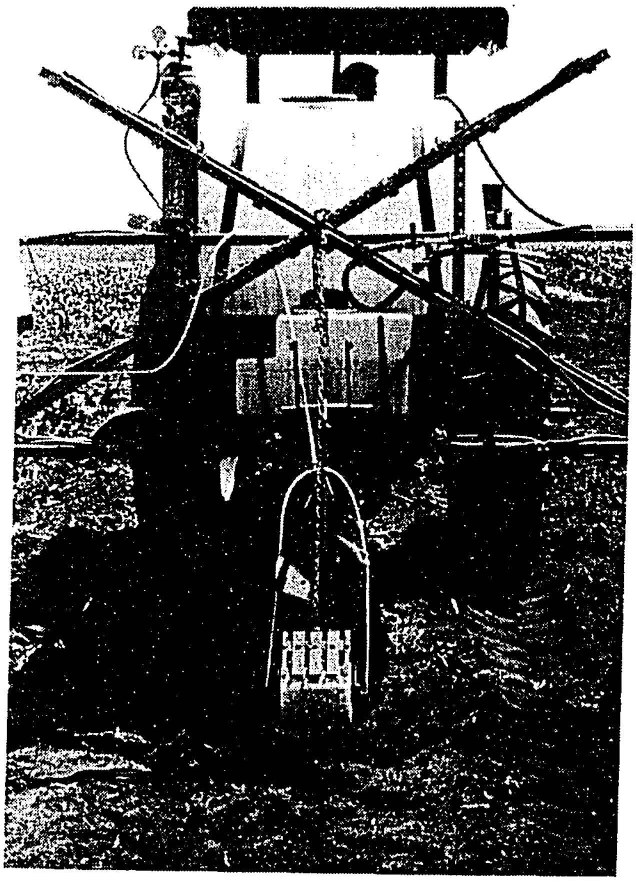

Figure 4.2: Point injector setup for persistence study

and collected immediately after herbicide application for an additional indicator of application rates. The plots were laid out in a completely randomized design.

Sample Collection and Analysis

Differences in persistence were measured by soil sampling over a three-week period, with samples taken daily for four days, every other day for eight days, and every third day for nine days (i.e. at 0, 1, 2, 3, 4, 6, 8, 10, 12, 15, 18, and 21 days after application). Two surfaces (bare soil or soil with surface crop residue) by two application methods (sprayed or injected) by three replications required twelve areas. At twelve samples per area, 144 soil samples resulted.

Soil samples were taken from a rectangular area the full width of the 20 cm band, 20 cm in length, and 5 cm in depth. These samples were placed in 4-L glass jars for extraction by using the organic solvent toluene, with mechanical mixing. For the residue plots, the corn residue was removed first and placed in separate 4-L jars from the soil. Extraction with distilled water and organic solvent toluene, with mechanical mixing, was used (Mastbergen,1987). Two samples were taken for each soil sample to determine the soil moisture content.

The extracts from the soil and residue samples were analyzed by using a Tracor 560 gas chromatagraph equipped with a model 702 N-P thermionic detector. The carrier gas was helium with a flow rate of 18 cc/min at a pressure of 276 kPa (40 psi). Reaction gases were hydrogen with a flow rate of 3.5 cc/min at a pressure of 276 kPa and air with a flow rate of 100 cc/min at a pressure of 690 kPa (100 psi). Column oven temperature was held constant at $160^{o}C$ with a inlet temperature of $245^{o}C$ and a detector temperature of $245^{o}C$. The herbicides were separated using a 3% OV-1 0.63

cm X 1.8 m packed column. Samples were injected into the column using a Tracor 770 auto sampler, and detector response was analyzed using a Spectro-Physics 4270 integrator.

Herbicides used in this study were alachlor, atrazine, and propachlor, three common herbicides with a wide range of vapor pressures. An average of 1.0, 1.8, and 0.9 kg/ha for propachlor, atrazine, and alachlor were applied to the soil surface with the band sprayer. For the PIC, an average of 0.10, 0.29, and 0.13 kg/ha of propachlor, atrazine and alachlor were applied. It was discovered later that back pressure at the points and a rate calculation error had caused the smaller amount of herbicides to be applied with the PIC.

Results and Discussion

The PIC functioned well both on the bare and the residue covered plots. Little plugging of the injection points was visible when using a line pressure of 140 kPa. The scraper between the points kept the clods and residue from interrupting the rotation of the wheel. Since the liquid herbicide flow was started before the injection wheel was lowered into the ground, and was left on for a short period of time after the wheel was raised, it was difficult to known exactly how much chemical was actually being applied until soil samples were analyzed. As it turned out, less chemical was applied with the PIC as compared to the band sprayer unit. The results were normalized to a constant amount of herbicide applied on day 0 in order to do a relative comparison between the two application systems.

The relative persistence values for atrazine, alachlor, and propachlor are compared when using two different application methods in Figures 4.3 and 4.4. The ratio of herbicide concentrations for PIC plots to that of the band sprayed plots is shown to 21 days after application. For example, if the same concentration is found in the soil for both the banded plots each day after application, the relative amount would be 1.0 from day 0 to day 21. If the line is above 1.0, there is a higher concentration in the PIC plots than in the band sprayed plots. If the line goes below 1.0, the band sprayed plots have a higher concentration. It is important to note that 0.28 cm of precipitation was received on day 2 after application, and 5.6 cm more rainfall fell between day 6 and day 10 (Figure 4.5).

Figure 4.3 shows a comparison of this ratio for the plots that had no crop residue on the surface(bare soil). The relative persistence is shown to be higher for propachlor when using the point injector. Propachlor concentrations are as much as 13 times higher for the PIC plots as compared to the band sprayed plots. Propachlor has a higher vapor pressure and therefore is more susceptible to volatilization losses. High propachlor losses are shown to occur during the high precipitation period, from day 6 to day 10. This most likely is due to a flush of microbial activity or the losses in surface runoff water and sediment. Alachlor concentrations are 2 times as great with the PIC plots for days 15 through 18. Increased soil temperatures (Figure 4.6) in the top 5 cm of the soil profile, during this period of time, may have increased microbial activities, and break down or enhanced volatilization of the alachlor closer to the surface.

Similar trends are found in Figure 4.4, where the plots were covered with an average of 79 percent corn residue. Ratios higher that 1 indicate that the injected herbicides tend to persist at higher concentrations when compared to surface applied herbicides. This also corresponds to previous research which shows greater volatiliza-

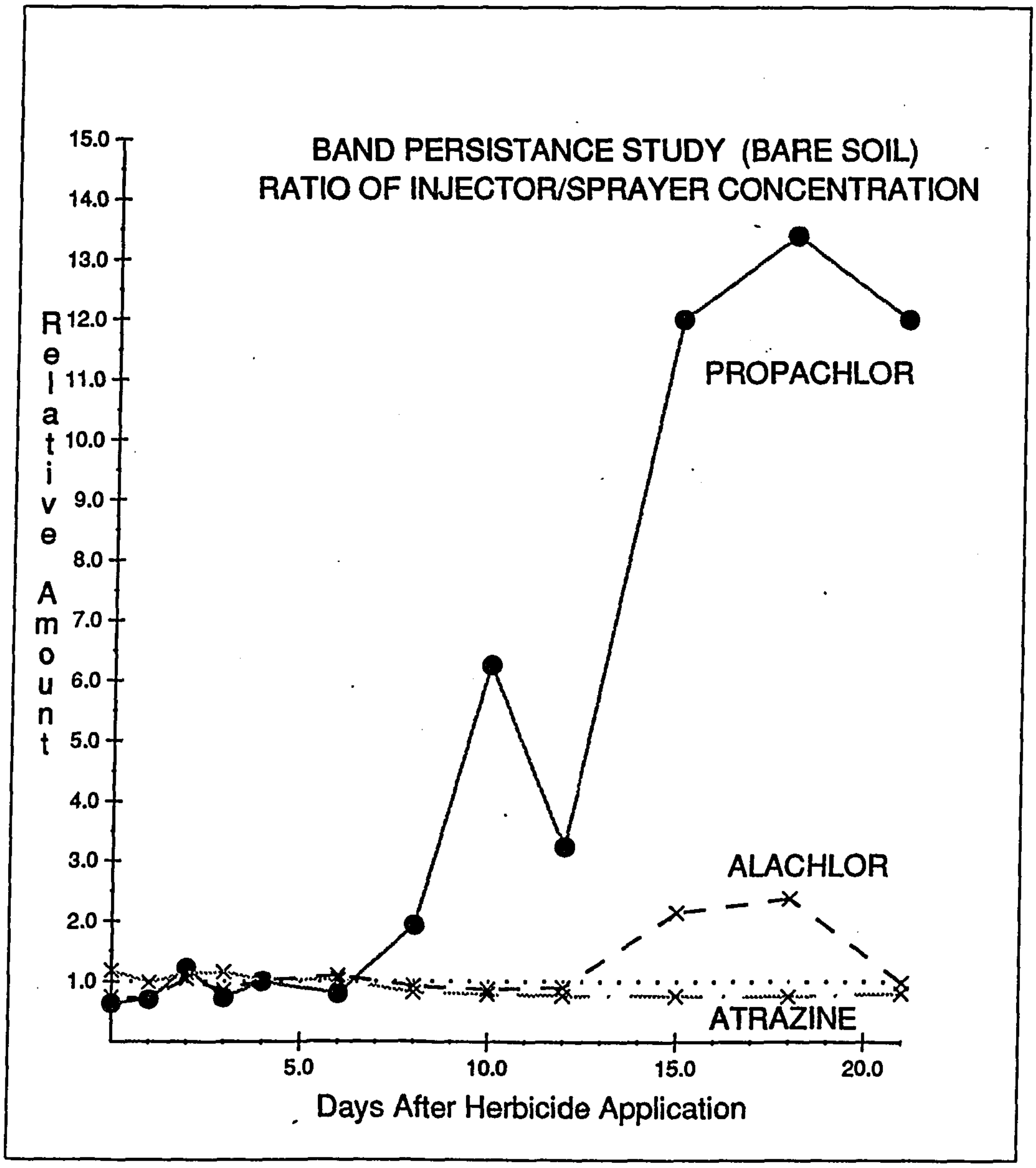

Figure 4.3: Relative persistence of herbicides relative to application methods on a bare soil

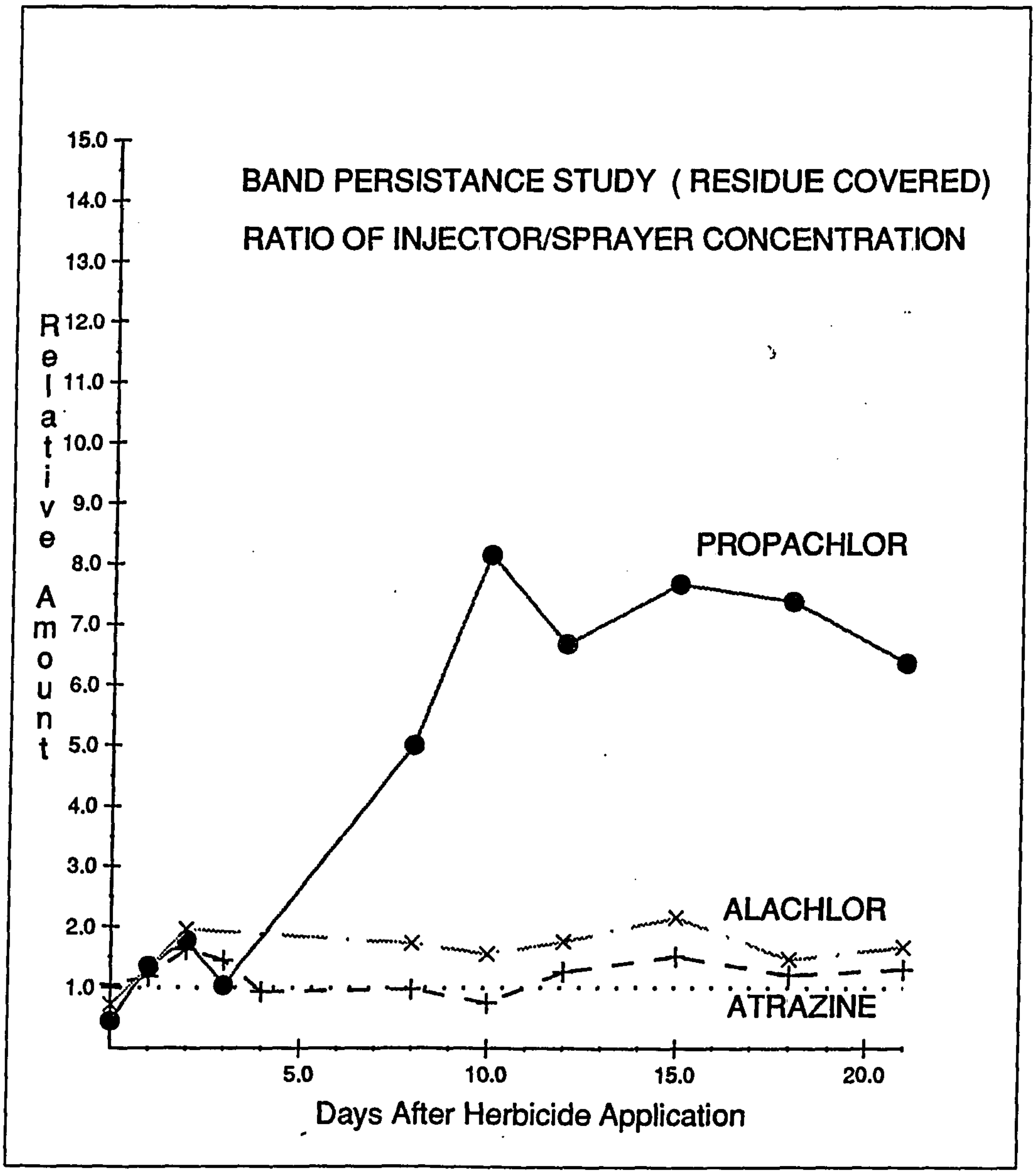

Figure 4.4: Relative persistence of herbicides relative to application methods on a corn residue covered soil

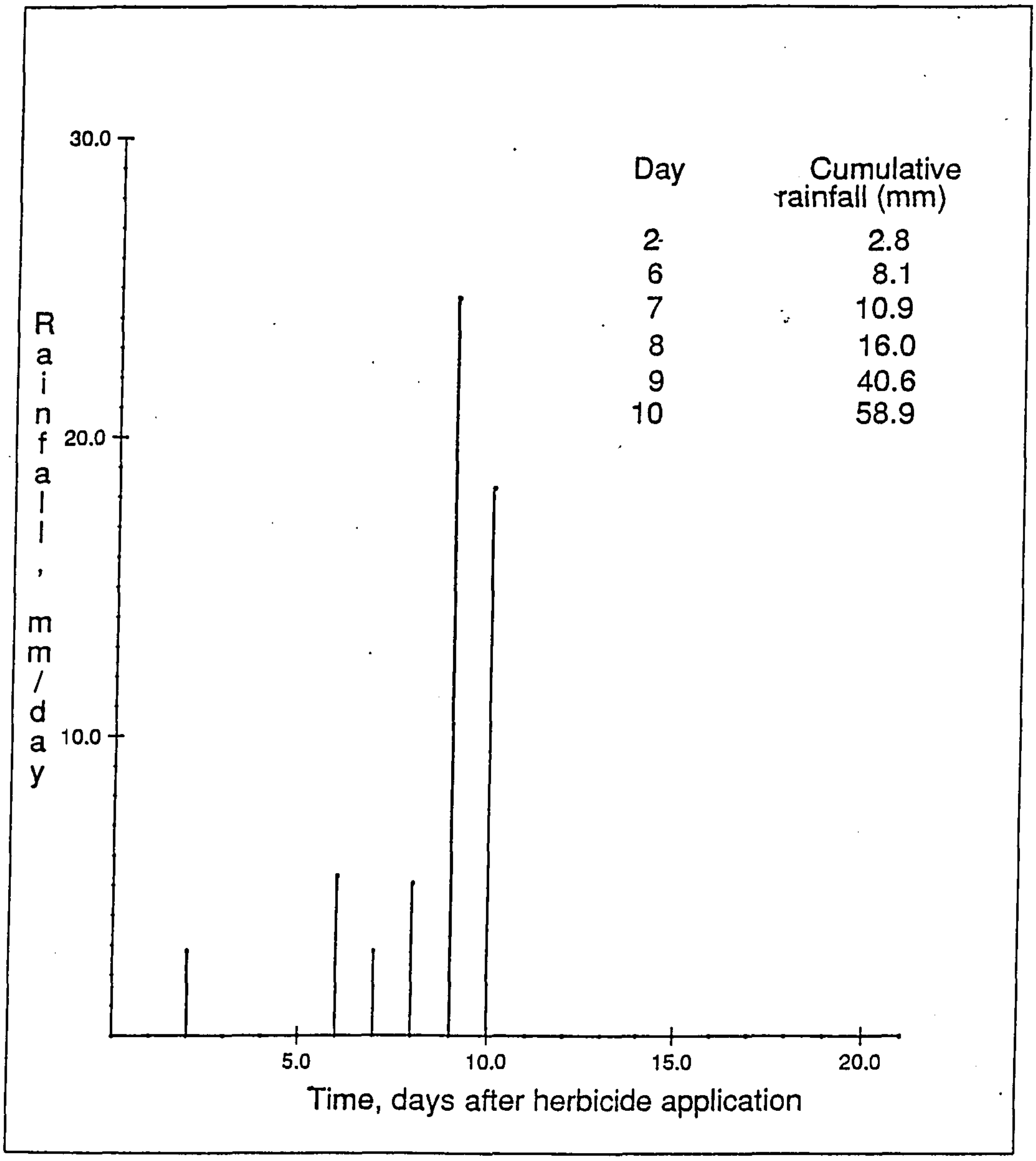

Figure 4.5: Rainfall record for the 21 day persistence study

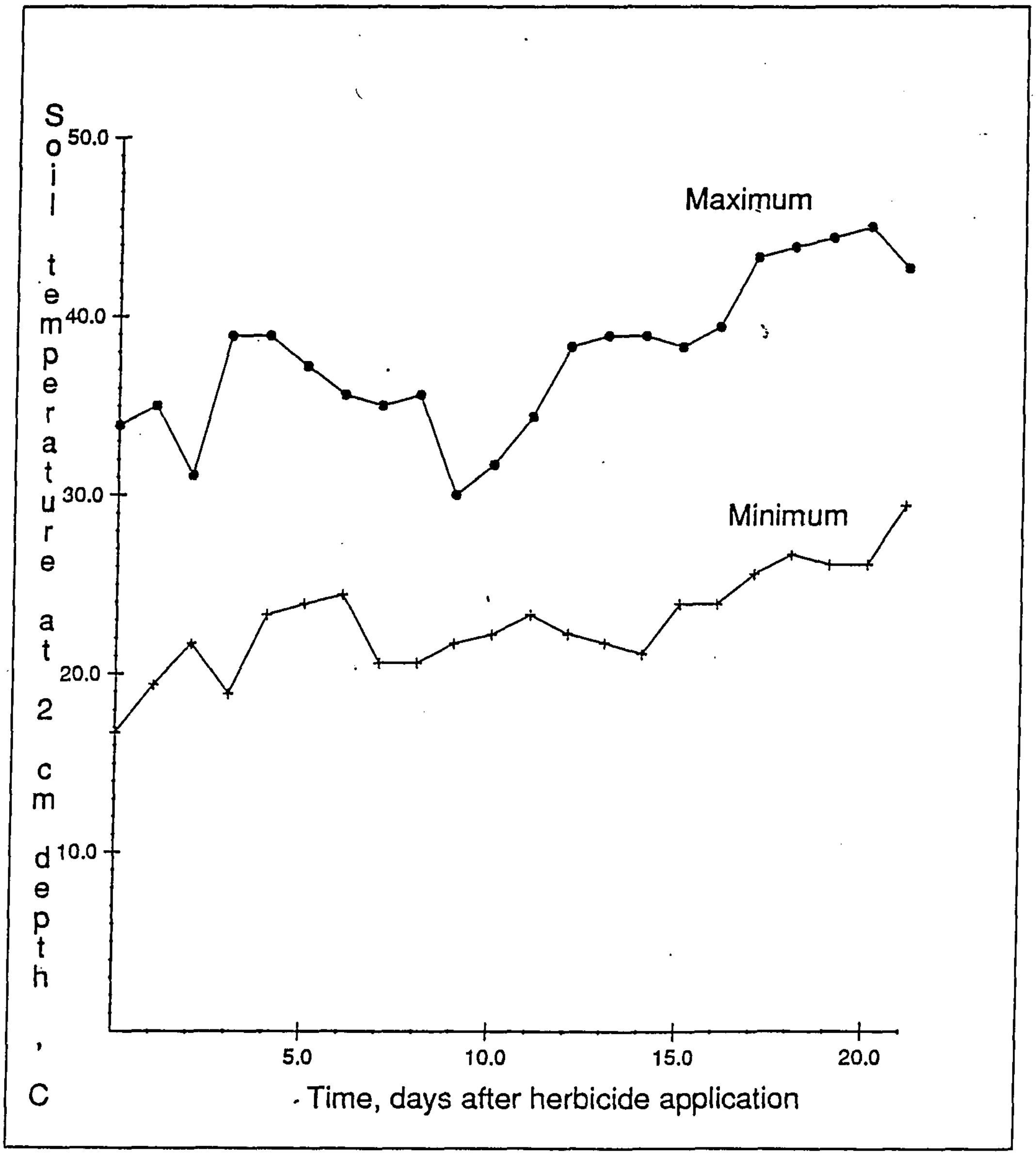

Figure 4.6: Soil temperature record for the 21 day persistence study

Table 4.1: The percentage of herbicide remaining 21 days after application

Treatment	% Propachlor	% Atrazine	% Alachlor
Bare-Injected	59.5	44.5	17.5
Bare-Sprayed	6.7	55.3	27.3
Residue-Injected	51.3	79.3	36.7
Residue-Sprayed	8.3	55.7	21.7
—— Contrast:——			
BI vs BS	**	N.S.	N.S.
RI vs RS	**	*	N.S.

** Indicates significance at the 1% level
* Indicates significance at the 10% level
N.S. No significance

tion and runoff losses occur when herbicides are applied to crop residue. Twenty-one days after application, atrazine concentrations are about the same for both application methods. Alachlor concentration are almost 2 times higher for the injected plots, and propachlor concentrations are over 6 times higher for the injected plots.

Table 4.1 compares the percentages of the herbicides remaining at the end of the 21 day study period for the various surface cover/application method combinations. Significant differences at the 1 percent level are found when comparing the injected plots and the surface sprayed plots for the herbicide propachlor. Whether the surface had a bare surface or corn residue covered surface, the injected plots significantly reduced the losses to the environment. Over 50 percent of that applied on either surface cover still remained on day 21 for the injected plots, whereas less than 10 percent of the propachlor remained on day 21 for the sprayed plots. Atrazine levels on day 21 are shown to be significantly higher for the residue-injected plot when compared to the residue sprayed plots at the 10 percent level.

The percentages of alachlor, atrazine, and propachlor remaining 21 days after application for both the residue covered and bare surface plots are shown in Figures 4.7 through 4.18. Figures 4.7 and 4.8 show the daily percent remaining broken into a residue and a soil component. The PIC effectively placed this herbicide beneath the corn residue, as can be seen on day 0. Less than 10 percent of the alachlor applied was found on the residue, while 35 percent of that applied with the sprayer was found on the residue. No more that 64 percent of that applied with the sprayer ever made it to the soil surface. Even though there was no significant difference found for the percent alachlor remaining on day 21 between the application methods, the PIC plots did contain a much higher concentration in the soil over the 21 day period. This would improve alachlor's weed control effectiveness.

The percent of alachlor remaining in the bare surface plots is shown in Figures 4.9 and 4.10. Both the injected and sprayed plots had approximately 18 percent of the alachlor applied left in the soil 21 days after application. Trends in losses over the study period were similar for both the PIC and sprayed plots. Low concentration levels on day 10 correspond to the high rainfall levels prior to and on day 10. This lower concentration on day 10 could be due to sampling difficulties on that day due to wet field conditions.

Figures 4.11 and 4.12 show the percent atrazine remaining over the 21 day period for the residue plots, while Figures 4.13 and 4.14 illustrates that remaining for the bare plots. As indicated in Figure 4.12, approximately 50 percent of the atrazine sprayed on the plots was retained by the residue. Even by day 8, 23 percent of the total 68 percent of the atrazine remaining was still being held by the corn residue. The heavy rain on days 9 and 10 finally washed a majority of the atrazine off of the residue. No more that 55 percent of that applied ever was found in the soil. The

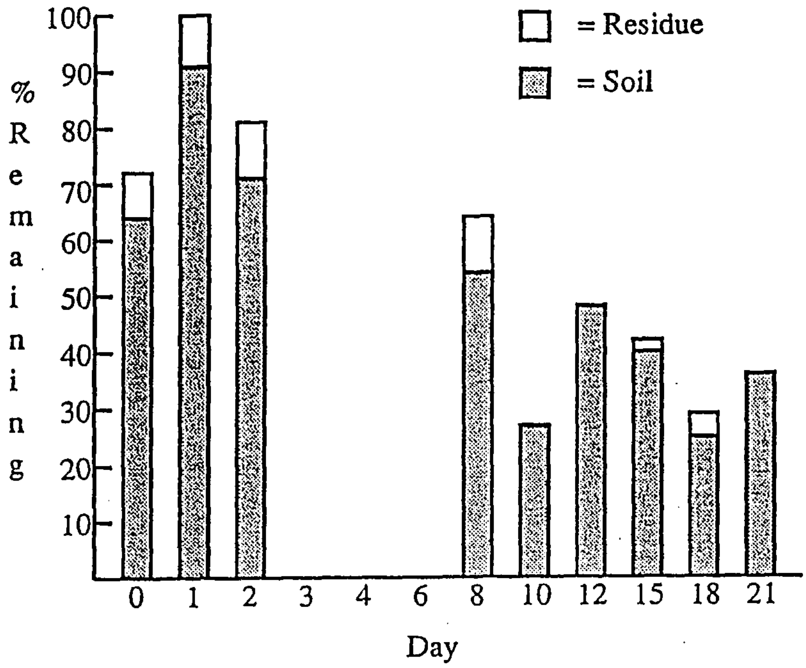

Figure 4.7: Percent of alachlor remaining after point injection on a corn residue covered soil

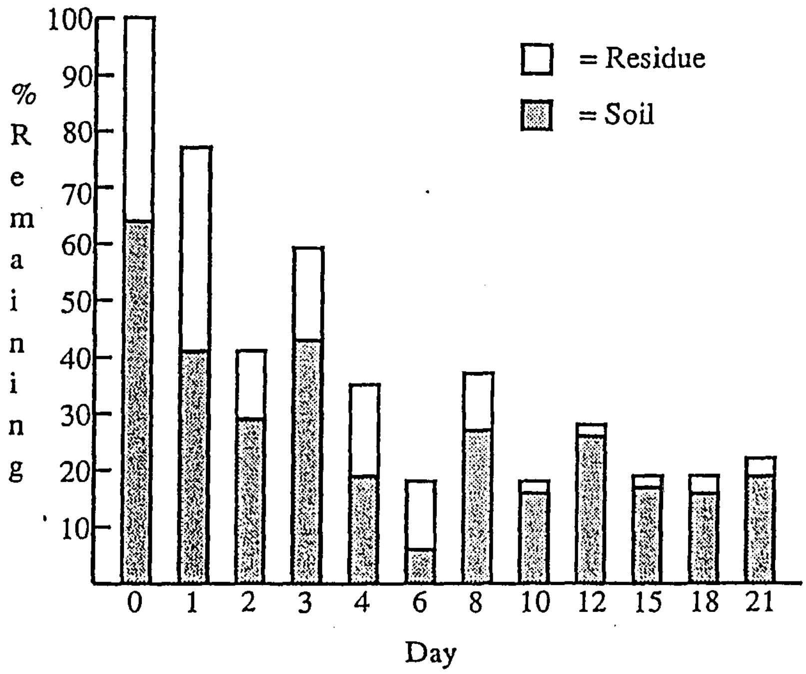

Figure 4.8: Percent of alachlor remaining after a surface spray application on a corn residue covered soil

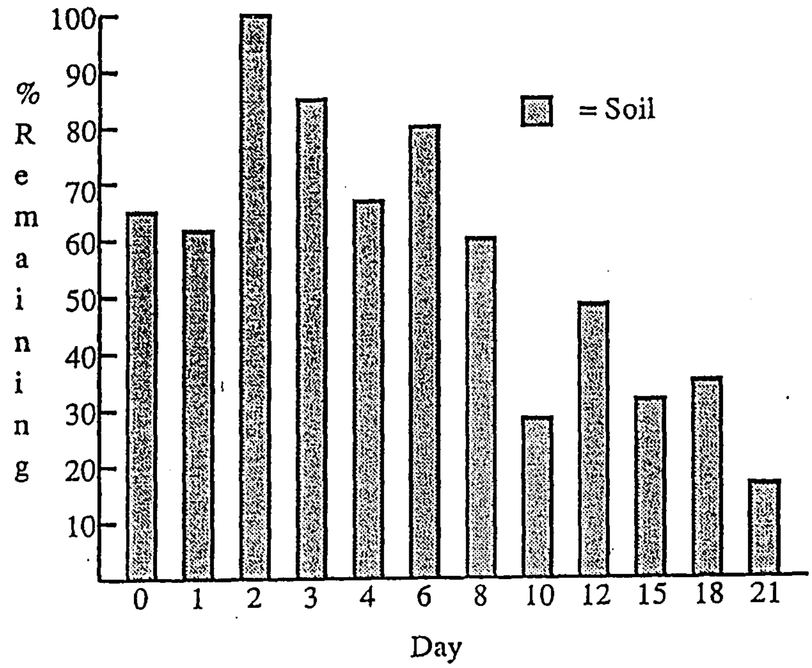

Figure 4.9: Percent of alachlor remaining after point injection on bare soil surface

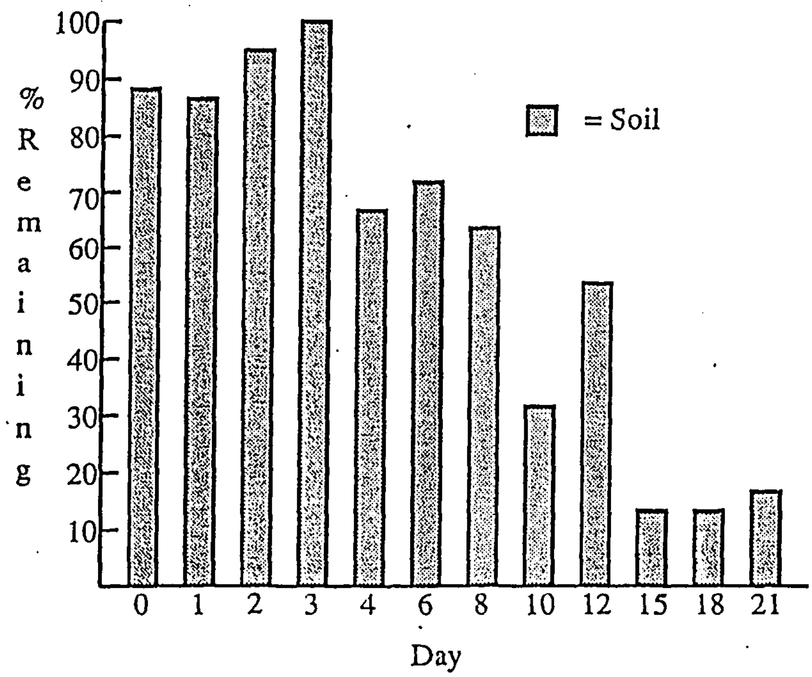

Figure 4.10: Percent of alachlor remaining after a surface spray application on bare soil surface

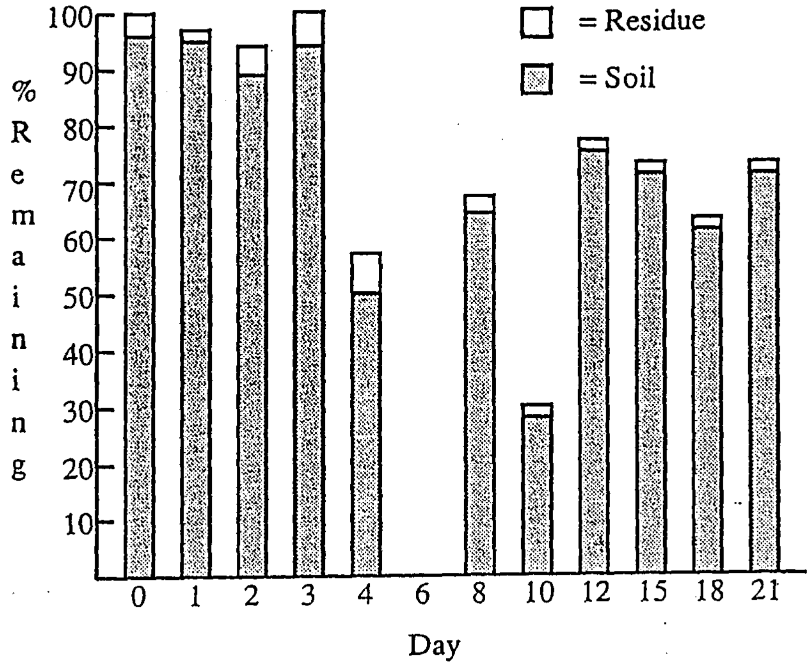

Figure 4.11: Percent of atrazine remaining after point injection on a corn residue covered soil

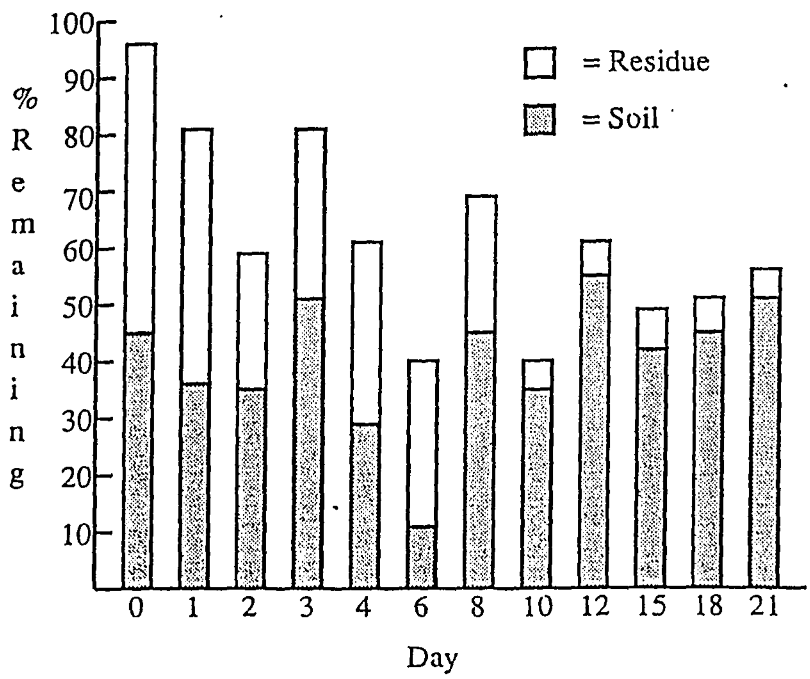

Figure 4.12: Percent of atrazine remaining after a surface spray application on a corn residue covered soil

PIC (Figure 4.11) did an effective job of placing the atrazine into the soil, with 96 percent of that applied located in the soil and only 4 percent found in the residue. By day 21, 71 percent of that applied on the first day was still present. Day 10 once again shows possible sampling problems due to the wet field conditions on that day.

The bare plots (Figures 4.13 and 4.14) displayed similar trends for both the PIC and sprayed plots. Both application methods had approximately 50 percent of the atrazine applied still in the soil on day 21.

Finally, the percent propachlor remaining after application is shown in Figures 4.15 and 4.16 for the residue plots and in Figures 4.17 and 4.18 for the bare surface plots. The PIC was effective in applying a majority of propachlor into the soil, whereas the sprayed residue plots had as much as 67 percent of the propachlor recovered found in the corn residue. A large change between day 1 and 2 can probably be attributed to the small rainfall on day 2. If the propachlor was washed off the residue onto the soil, one would expect to see an increased concentration in the soil; however, this was not the case for either the injected plots or the sprayed plots. Therefore, it can be concluded that the rain increased the degradation or volatilization of the propachlor. On day 2 for the sprayed plots, only 22 percent of that applied was still remaining, and by day 21 less than 10 percent remained. The PIC significantly reduced the losses to the environment. Fifty-one percent of that applied still remained on the last day of the study.

The PIC also significantly reduced the losses of propachlor to the environment for the bare surface plots, as illustrated in Figure 4.17. Approximately 60 percent of the propachlor applied on the first day was still in the soil on day 21. The sprayed plots had large losses following the rainfall events on day 9 and day 10. No more that

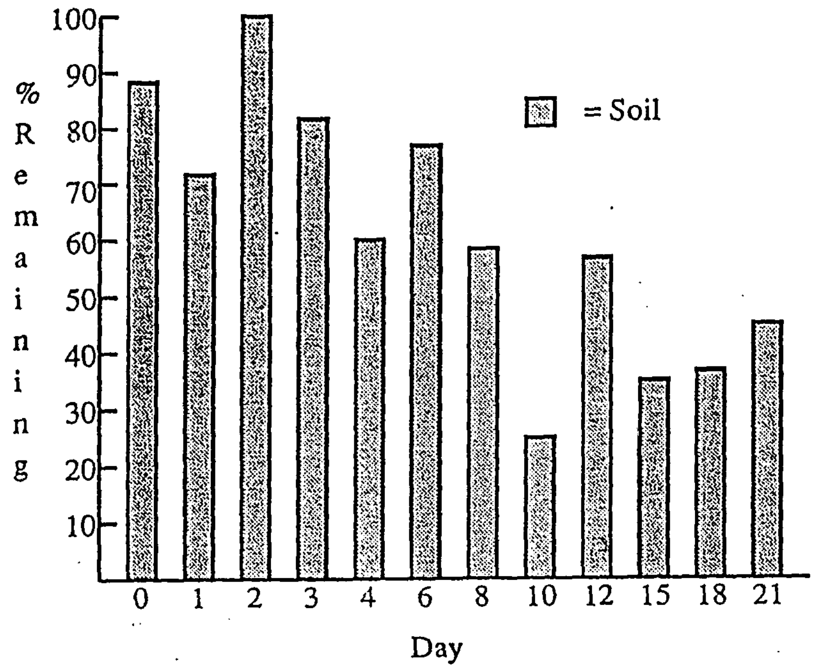

Figure 4.13: Percent of atrazine remaining after point injection on a bare soil surface

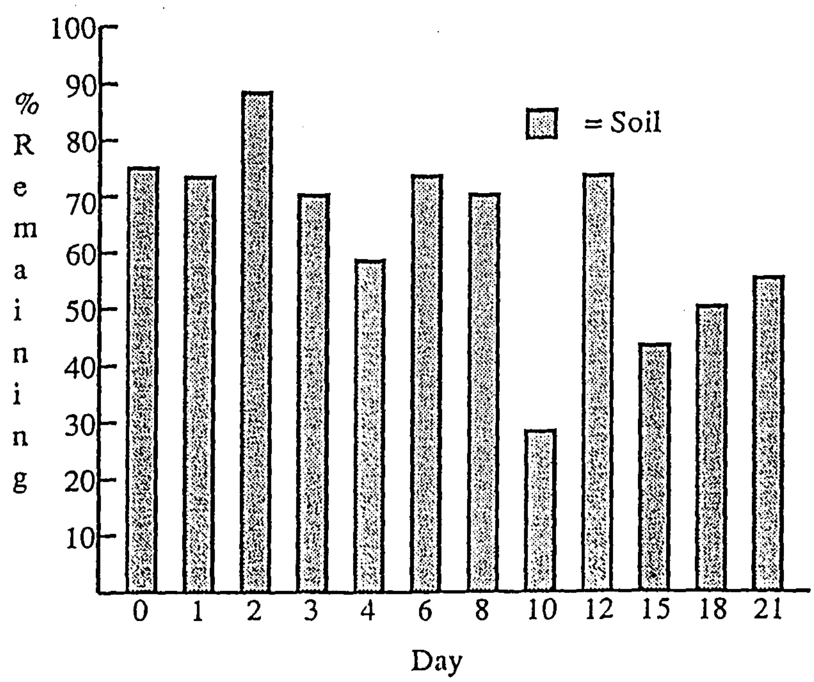

Figure 4.14: Percent of atrazine remaining after a surface spray application on a bare soil surface

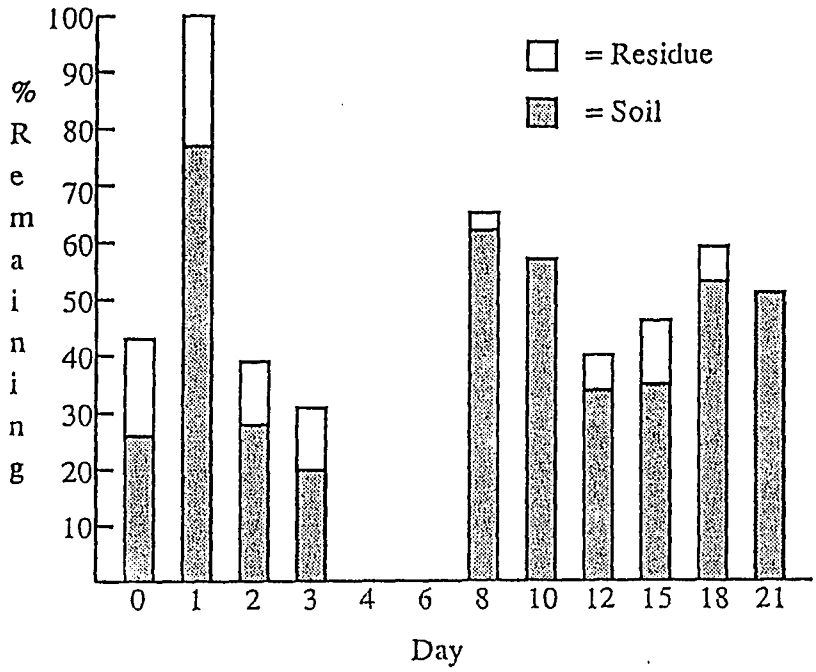

Figure 4.15: Percent of propachlor remaining after point injection on a corn residue covered soil

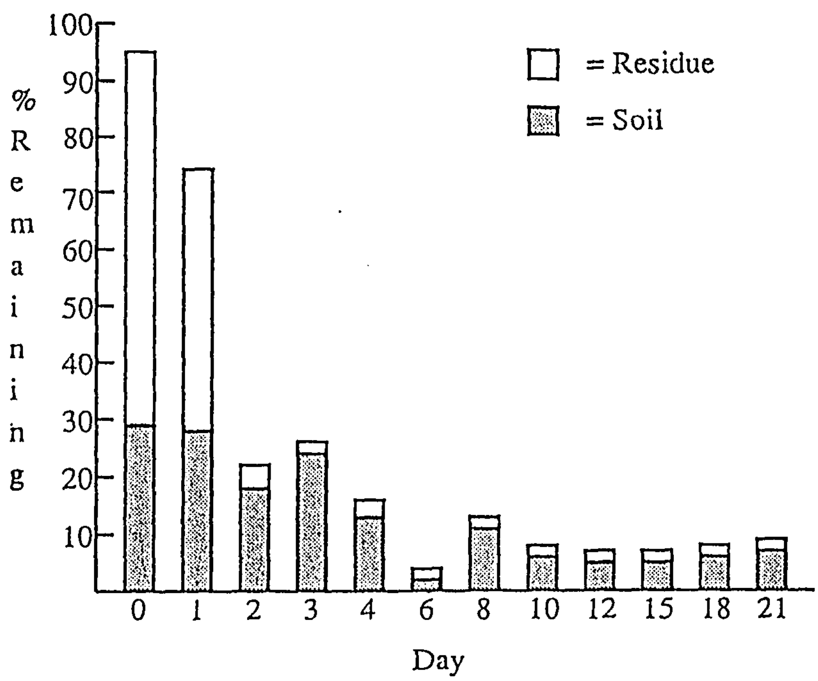

Figure 4.16: Percent of propachlor remaining after a surface spray application on a corn residue covered soil

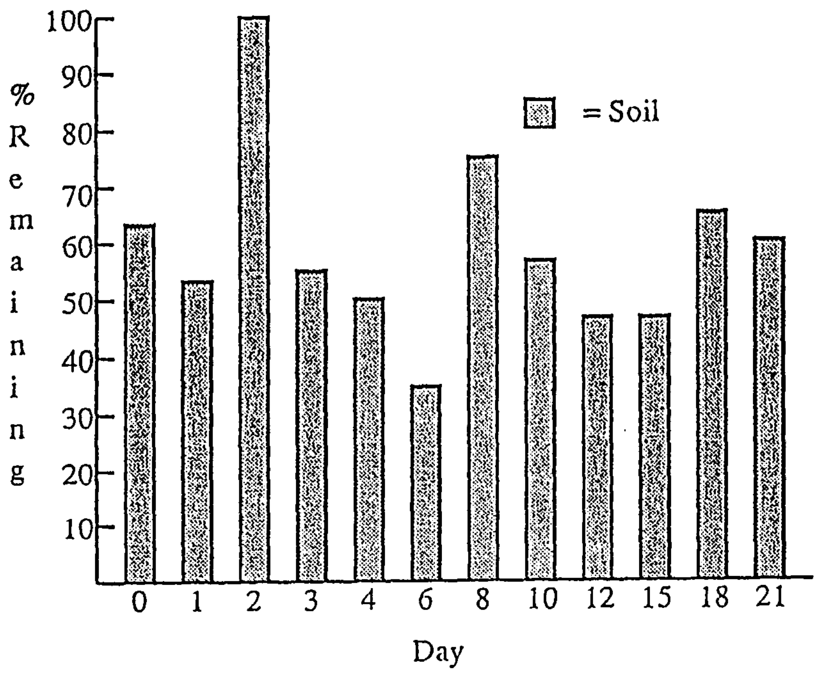

Figure 4.17: Percent of propachlor remaining after point injection on a bare surface

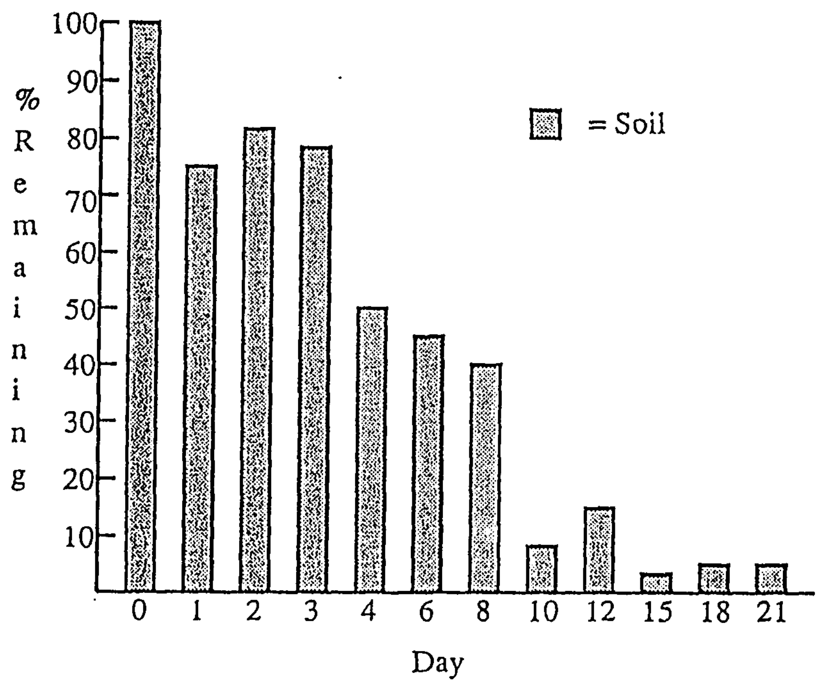

Figure 4.18: Percent of propachlor remaining after a surface spray application on a bare soil surface

14 percent of that applied was ever detected in the soil following day 10.

When trying to model the degradation of each of the three herbicides in this study, the exponential decay model was found to be useful in only a few cases. The concentrations of the herbicides in soil versus time were fitted using a non-linear technique and iterative method to find the least squares estimates for the non-linear models. An equation of the form,

$$concentration = Ae^{bt}$$

where A and b were the constants, and t was the time after herbicide application, was used for predicting the persistence of each herbicide. Propachlor sprayed on the bare surface and residue covered plots tended to follow the exponential decay model more closely that did either of the other herbicides. The r^2 values ranged from 0.77 to 0.91 for the six propachlor replications. There was not similar evidence that the other herbicides followed the exponential decay model.

A stepwise regression was also used to see if a multivariable linear fit of the degradation could be found when using soil, and weather data. Variables used included: time(DAY), rain(RAIN), gravimetric moisture content(MC), minimum soil temperature(MNST), maximum soil temperature(MXST), minimum air temperature(MNAT), maximum air temperature(MXAT), and pan evaporation(PEVAP). Only the terms that were significant at the 0.15 level were included in the linear equation (Helwig, 1985). Those terms that appear first in the linear equation have a higher probability of contributing to the degradation behavior of the herbicide than those that follow it.

Tables 4.2 and 4.3 show the resulting equations plus coefficients found when fitting the data with both statistical methods.

Table 4.2: A summary of curve fitting techiques[a] for residue covered plots

Herbicide	Application	Replication	Equation	r^2
Propachlor	Injection	1	$.005 * DAY - .008 * MXAT + .25$	0.85
Propachlor	Injection	2	$.006 * RAIN + .006 * MNST - .0005 * MXST - .07$	1.00
Propachlor	Injection	3	$-.022 * MNAT + .02 * MNST + .002 * RAIN - .009 * PEVAP + .08$	1.00
Propachlor	Sprayed	1	$.89 * e^{-.38 * DAY}$	.91
Propachlor	Sprayed	2	$1.13 * e^{-.38 * DAY}$	0.89
Propachlor	Sprayed	3	$2.04 * e^{-1.11 * DAY}$	0.85
Atrazine	Injection	1	$.004 * MXAT - .032$	0.48
Atrazine	Injection	2	$nofit$	-
Atrazine	Injection	3	$-.022 * DAY + 0.03 * MXAT$	0.91
Atrazine	Sprayed	1	$-.02 * MC - .17 * PEVAP - .01 * RAIN + 2.0$	0.81
Atrazine	Sprayed	2	-.09*MNAT+2.72	0.44
Atrazine	Sprayed	3	$-.13 * MNAT + 3.01$	0.69
Alachlor	Injection	1	$.089 * e^{-.058 * DAY}$	0.83
Alachlor	Injection	2	$.076 * e^{-.038 * DAY}$	0.27
Alachlor	Injection	3	$-.008 * MNAT + .17$	0.48
Alachlor	Sprayed	1	$-.366 * PEVAP - .04 * MC + 0.2 * MXST + 1.5$	0.94
Alachlor	Sprayed	2	$-.10 * MNAT + 2.17$	0.81
Alachlor	Sprayed	3	$-.143 * MNAT + 0.07 * MNST + .013 * MC + .65$	0.89

[a] Helwig (1985).

Table 4.3: A summary of curve fitting techiques[a] for bare soil plots

Herbicide	Application	Replication	Equation	r^2
Propachlor	Injection	1	$.005 * DAY - .008 * MXAT + .25$	0.85
Propachlor	Injection	2	$.006 * RAIN + .006 * MNST - .0005 * MXST - .07$	1.00
Propachlor	Injection	3	$-.022 * MNAT + .02 * MNST + .002 * RAIN - .009 * PEVAP + .08$	1.00
Propachlor	Sprayed	1	$.89 * e^{-.38*DAY}$	.91
Propachlor	Sprayed	2	$1.13 * e^{-.38*DAY}$	0.89
Propachlor	Sprayed	3	$2.04 * e^{-1.11*DAY}$	0.85
Atrazine	Injection	1	$.004 * MXAT - .032$	0.48
Atrazine	Injection	2	*nofit*	-
Atrazine	Injection	3	$-.022 * DAY + 0.03 * MXAT$	0.91
Atrazine	Sprayed	1	$-.02 * MC - .17 * PEVAP - .01 * RAIN + 2.0$	0.81
Atrazine	Sprayed	2	-.09*MNAT+2.72	0.44
Atrazine	Sprayed	3	$-.13 * MNAT + 3.01$	0.69
Alachlor	Injection	1	$.089 * e^{-.058*DAY}$	0.83
Alachlor	Injection	2	$.076 * e^{-.038*DAY}$	0.27
Alachlor	Injection	3	$-.008 * MNAT + .17$	0.48
Alachlor	Sprayed	1	$-.366 * PEVAP - .04 * MC + 0.2 * MXST + 1.5$	0.94
Alachlor	Sprayed	2	$-.10 * MNAT + 2.17$	0.81
Alachlor	Sprayed	3	$-.143 * MNAT + 0.07 * MNST + .013 * MC + .65$	0.89

[a]Helwig (1985).

The air temperature (MNAT and MXAT)seemed to have the highest correlation with degradation of all the herbicides sprayed or injected on the residue plots. For the sprayed herbicides the minimum air temperature(MNAT) was found to be the most significant factor in the majority of the fits. Moisture content for the sprayed plots also showed up several times as significant factor in the herbicides degradation. The air temperature (MNAT and MXAT) was more of a factor in the degradation of the injected plots, although no one factor was consistently found in a majority of the equations. This seems to indicate that as temperature increases, these herbicides applied to the corn residue surface tend to degrade or volatilize faster. For the bare plots, the major factors were time(DAY), rainfall amounts(RAIN), and evaporation(PEVAP).

Conclusions

1. The PIC functions effectively on both bare soil surfaces and on surfaces covered with as much as 79 percent corn residue. Line pressures of at least 140 kPa and a scraper for cleaning out the debris between the injector points are necessary for reducing the potential of point plugging.

2. No significant difference in persistence was found between application methods of subsurface injection and surface spraying for the herbicides atrazine and alachlor. Losses of propachlor from the sprayed plots, with either corn residue cover or a bare surface, were significantly higher when compared to the injected plots. The percent of propachlor remaining 21 days after application was found to be 12 times higher for the bare surface plots and 6 times higher for the residue covered plots. The high losses for the surface applied propachlor seemed to be highly correlated to the rainfall and its effects on the volatilization, degradation, and surface runoff amounts.

3. The PIC placed a majority of the herbicides beneath the corn residue during application. The sprayer left as much as 36, 53, and 71 percent of the alachlor, atrazine, and propachlor, respectively, applied on the first day on the corn residue. The injector therefore was successful in reducing the potential for volatilization losses.

4. The decrease in concentration of the herbicides was closely fitted by using either a non-linear curve fitting approach with an equation of the form:

$$Concentration = Ae^{bt}$$

or by using a multivariable linear curve fitting approach. Air temperature seemed to be the most significant variable for the injected plots covered by residue, whereas time and rainfall were more significant for the injected plots with no residue cover.

CHAPTER 5. THE EFFECT OF BAND INJECTION OF HERBICIDES ON RUNOFF AND LEACHING LOSSES

Introduction

Losses of herbicides with water and sediment in surface runoff is of concern both economically for the farmer and environmentally for both the farmer and the general public. A considerable amount of research has been conducted to determine how herbicides are lost during a rainfall event, and how to reduce these losses. Rainfall simulation has been one of the most common methods for studying runoff and erosion losses (Barnett et al., 1967; White et al. 1976; Baker et al., 1978; Barisas et al., 1978; Baker and Laflen, 1979; Trichell et al, 1969; Ahuja, 1982; Ahuja and Lehman, 1983; Mickelson, 1984; Laflen et al., 1991). Several models have also been developed to predict herbicide losses with surface runoff and eroded soil (Heathman et al., 1986; Baker, 1985; Lorber and Mulkey, 1982; Heathman et al., 1985; Steenhuis and Walter, 1980; Leonard et al., 1979; Laflen et al., 1991; Foster, 1991; Renard et al., 1991).

Rainfall simulation studies have shown that the highest herbicide concentrations in runoff occur early in a rainfall event and decrease during the duration of the simulated storm. Highest losses occur for rainfall events that occurred shortly after herbicide application. White et al. (1976) found that "surface runoff levels were highest for the first runoff event after herbicide application each year, and initial concentrations were related to the time lapse between herbicide application and the date of the first runoff event," when studying the loss of 2,4-D from a small agricultural watershed. The same comments were made by Baker and Johnson (1979) when studying the runoff losses of alachlor, atrazine, and cyanazine. In this rainfall simulation study, "80 to 90 percent of the average herbicide losses were with water." Conservation tillage systems were found to decrease runoff and erosion (and herbicide losses), although the herbicide concentrations in water and/or sediment were sometimes higher for conservation tillage relative to moldboard plow tillage.

Since most herbicides are at least moderately adsorbed to soil, concentrations of herbicides in sediment tend to be higher than those in the water. Haan (1971) conducted a rainfall simulation study looking at the runoff losses of aldrin, dieldrin, and DDT. It was discovered "that the concentration of the pesticides in the eroded soil was on the order of 10 to 30 ppm while that in the runoff water was only 1 to 70 ppb." Similar findings were reported by Baker and Laflen (1979) when studying the effect of wheel tracks and incorporation on runoff losses of surface-applied herbicides. Even though the herbicide concentrations in sediment were as much as 4 times higher than in runoff water, 82 to 89 percent of the herbicide losses were in solution. Total losses of alachlor, atrazine, and propachlor were about 3.7 times greater for the plots with wheel-tracks versus those without. The incorporated herbicide plots losses were approximately 3.5 lower than those plots with no incorporation and no wheel-tracks. Therefore herbicides which were incorporated had the lowest runoff losses.

Herbicides losses in most of the runoff studies seldom were found to be over 10 percent of that which was applied (Hall et al., 1983; Baker and Laflen, 1979; Baker et al., 1978; Hall et al., 1972; Trichell et al., 1968; Hartwig and Hall, 1980). Hartwig and Hall (1980) stated that "Generally, wettable powder, flowable and dry flowable herbicide losses up to 5 percent of that applied can be expected from fields with a 10 to 15 percent slope. Fields with a slope of 3 percent or less will commonly not have herbicide losses greater than 2 percent of that applied."

Several researchers have studied the mixing effect of rainfall water with the chemical solution in the top soil layer and its relationship to the chemical transfer of herbicides to runoff water (Heathman et al.,1985, 1986; Aluja and Lehman, 1983; Ahuja, 1982; Steenhuis and Walter, 1980; Leonard et al., 1979; Baker, 1980). Heathman et al. (1985) used a non-uniform mixing model to predict the transfer of herbicides to surface runoff. "The model incorporates the varying degree of mixing with depth between rainwater and soil during the chemical transfer process, as well as the effects of infiltration on chemical movement into the soil before and after runoff begins." The adsorption-desorption process for weak to moderately adsorbed chemicals was represented by the equation

$$C_S = \alpha C \tag{5.1}$$

where:

- C_S = concentration of chemical in the adsorbed phase on soil particles
- C = chemical concentration in soil solution
- α = constant.

The degree of mixing between the rainfall and the soil solution was assumed to decrease exponentially with soil depth, starting from the time runoff began:

$$\beta = e^{-bz} \tag{5.2}$$

where:

- β = degree of mixing between rainfall and soil solution
- b = constant
- z = soil depth (maximum depth of soil interaction with rainfall is taken to be less than 2.0 cm).

Most researchers agree that the mixing zone is probably less than 2 cm below the soil surface. "One factor that affects this depth of interaction is the mixing caused by raindrop splash, both temporary suspension of soil and localized high hydraulic pressure areas" (Baker, 1980).

Residue has a major effect on raindrop impact, decreasing the mixing at the soil surface and therefore decreasing potential runoff and erosion losses (Mickelson, 1984; Heathman et al., 1986). Still losses of herbicides applied to no-tillage fields can be high due to the high concentration of the herbicides at the soil surface. Residue cover has been shown to increase water infiltration and to decrease erosion and runoff losses (Mickelson, 1984; Baker and Laflen, 1982; Baker et al.,1982; Laflen et al.,1978; Dickey et al., 1984; Kenimer et al., 1987).

When herbicides move down through the soil profile with water it is called leaching. Studies have shown that many commonly used herbicides are leaching into the ground water (Hallberg, 1986). Leaching of herbicides is affected by the solubility of the herbicide, adsorption of the herbicide in the soil, moisture content of the soil at the time of application, and amounts of evaporation between rains. Herbicide leaching has been found to be inversely proportional to the herbicide adsorption characteristics, field moisture capacity, organic matter and clay content, and cation-exchange capacity, whereas soil pH and water flux tend to be directly related to herbicide leaching (Helling, 1971).

The herbicides with a higher adsorption coefficient move slower through the soil profile than those with lower adsorption coefficients. Greater quantities of water would therefore be required to leach a herbicide with a large K or K_{OC} value to a given depth (Soil Conservation Service, 1983). Keller and Alfaro (1966) conducted a study on the effects of different continuous water application rates on leaching. Their results suggested that leaching losses of herbicides were increased by decreasing the water application rate.

When looking at the diffusion of herbicides in the soil profile, Ritter et al. (1973) found that the greatest amount of herbicide movement occurred with high temperatures and high moisture contents. An increase in bulk density tended to decrease the movement for all the herbicides studied.

Tillage has been shown to significantly affects the number of macropores and their effect on herbicide leaching losses (Boddy and Baker, 1990; Mukhtar et al., 1985). Mukhtar et al. (1985) compared the use of a Paraplow treatment with a moldboard plow, a chisel-plow, and a no-tillage treatment. The Paraplow loosened the soil but did not invert the soil surface. Infiltration was increased with the Paraplow due to its deep, surface connected cracks. The increased residue cover with the Paraplow and with the no-tillage treatments prevented surface sealing, and thus also increasing the soil water infiltration.

Boddy and Baker (1990) compared conservation tillage effects on nitrate and atrazine leaching. The tillage treatments included moldboard plow, chisel plow, and no-tillage. Soil columns, 20 cm in diameter and 30 cm deep, were collected from soils in each of the tillage treatments. Simulated rainfall was applied to the soil columns approximately 24 h after the chemicals were applied. A total of 7.5 cm of rainfall was applied to all of the columns using variations in timing, duration, and intensity. The results showed that drainage occurred sooner for the chisel plow treatments. Drainage also occurred sooner with the high intensity rainfall. Atrazine losses were highest with the chisel plow treatment. The largest loss was 0.089 percent of that which was applied. This occurred during the most intense rain which was preceded by a wetting rain. The highest initial concentration was 11 ppb. Overall, the leaching losses of atrazine for the chisel plow, the no-tillage, and the moldboard plow treatments were 0.082, 0.071, and 0.042 percent, respectively.

In the previous two chapters, a point-injection system for band application of herbicides was found to be effective in controlling weeds when using several preemergent herbicides, and was found to decrease losses to the environment when compared to band spraying on the soil surface. The objectives of this study were to determine the effects of band application of herbicides using either a point-injection system or a surface sprayer on herbicide concentrations and losses in surface runoff water and sediment, and on herbicide leaching.

Materials and Methods

Application Methods

Three tillage systems were considered in this study: chisel plow, flat no-till, and strip-tillage on ridges. The treatments for these tillage systems included subsurface band injection and surface band spraying of the herbicides atrazine, alachlor, and propachlor. The properties of these herbicides are shown in Table 5.1. The point-

Table 5.1: Properties of the herbicide used in the study[a]

Parameter	Atrazine	Alachlor	Propachlor
Trade Name	AATREX	LASSO	RAMROD
Molecular Formula	$C_8H_{14}ClN_5$	$C_{14}H_{20}ClNO_2$	$C_{11}H_{14}ClNO$
Molecular Weight	215.7	269.8	211.7
Water Solubility @25^oC (mg/L)	33	242	613
Vapor Pressure @25^oC (mm Hg.)	8 x 10^{-7}	2.2 x 10^{-5}	2.3 x 10^{-4}

[a]Weed Science Society of America (1983).

injection cyclinder (PIC) that was used is shown in Figure 5.1. Each point on the injector wheel was assumed to have a 1.25 cm effective radius of influence and was designed to inject the herbicides approximately 2.5 cm below the soil profile. The design and function of the point injector have been discussed in detail in the previous two chapters.

Plot Set-up

Plot areas (1.52 m x 9.14 m) were established in 1989 on a Nicollet silt loam soil. Measurements of herbicide losses, with surface runoff and leaching water, were made in the summer of 1990. Three replications were made for each treatment, thus 18 plots were needed (3 tillages X 2 applications X 3 replication = 18 plots). Figure 5.2 shows the plot layout. The no-tillage plots were laid out in an area that had been in

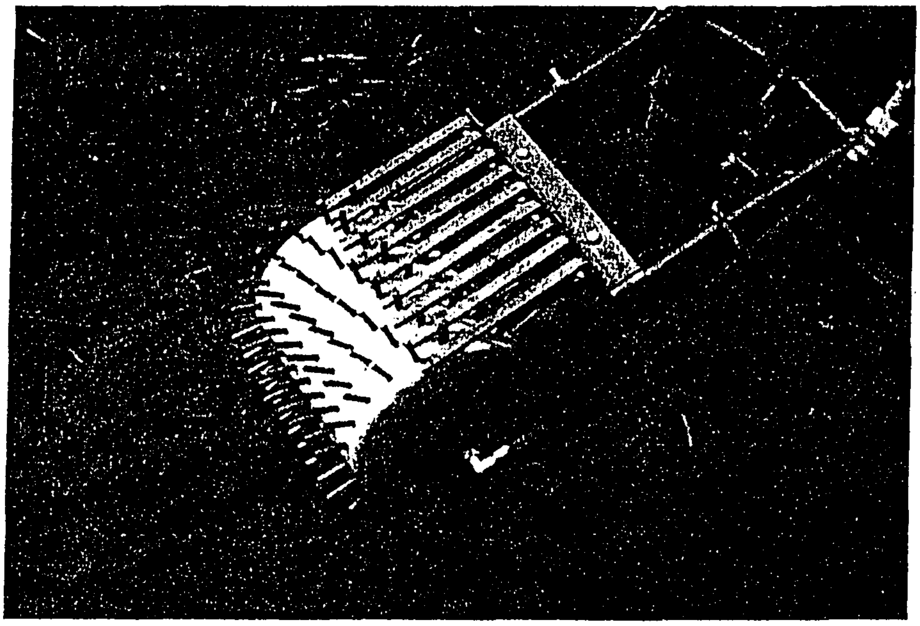

Figure 5.1: Point injector used for band application

no-till corn for more that 10 years. A randomized block design was used for comparing the application method for the no-tillage treatment. The average residue cover was found to be approximately 65 percent using the photo grid method (Laflen et al., 1981). The other plots were set up in an area that had ridges established the year before. These plots were also set up as in a randomized block design for statistical analysis perposes. The chisel plow tillage plots were chisel plowed and disked prior to herbicide application and rainfall. For the ridge tillage plots, the top of the ridges were leveled, using a hoe, to simulate having the ridge top cut off during a planting operations. The average residue covers for the ridge tillage and the chisel plow tillage plots were 40 and 12 percent, respectively.

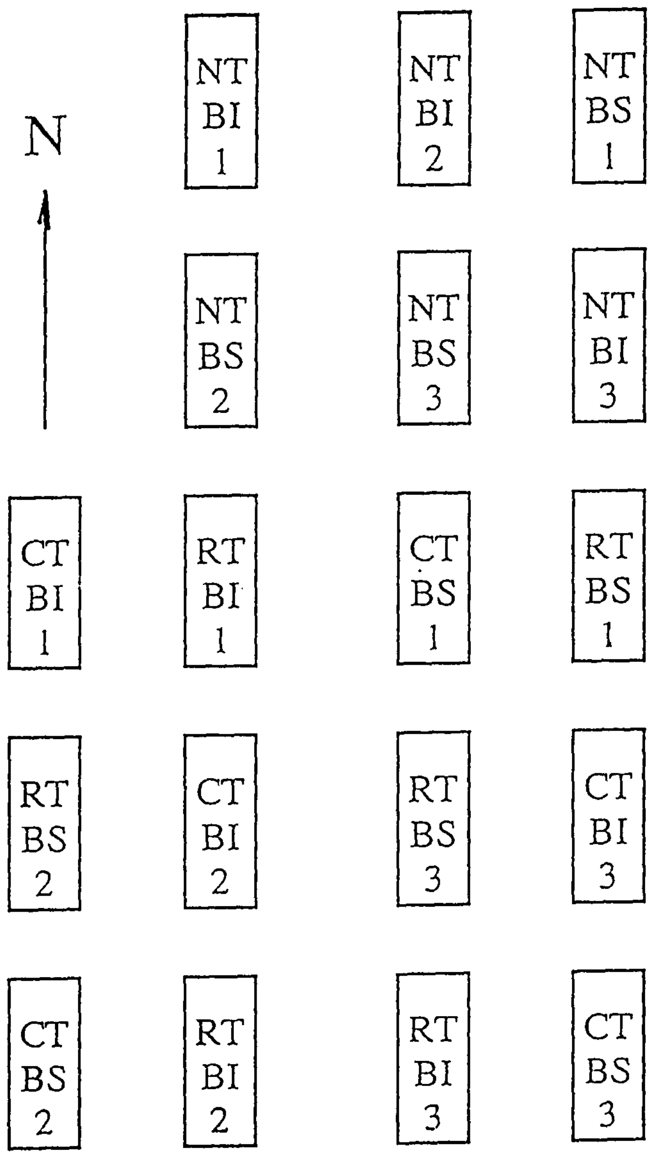

Figure 5.2: Plot layout for the rainfall simulation study

The plot boundaries were defined using a 20 cm high heavy gauge galvanized sheet metal pounded abount 10 cm into the ground. This set-up was to keep water from around the plot from entering and the runoff water within the plot from leaving except at the desired exit point. The plots were established parallel to the slope and the runoff was collected at the lower end of the plot using a galvanized chute. Inverted chutes were placed over the other chutes to keep additional rainfall from entering the runoff water and diluting the samples.

Prior to rainfall, three perforated poly vinyl chloride (PVC) pipes, 5 cm in diameter and 1.5 m in length, were installed (at a depth of about 45 cm) beneath the plot to collect water percolating out of the tillage zone (see Figure 5.3). Each pipe had 0.15 mm slots on the top half of the pipe for the whole length. In order to install these pipes, a back hoe was used to dig trenches perpendicular to the plots, about 1 m deep. A large drill with a 5 cm auger was then used to burrow a hole long enough for the 1.5 m PVC pipe to be inserted (Figure 5). A level was used with the auger to insure that a slight slope would be present with the pipes so that they would drain water toward an exit pipe. Both ends of the PVC pipe were plugged with appropriate sized rubber stoppers. The end of the pipe to which the water would drain had a rubber stopper that had a 9.5 mm hole drilled into it, with plastic tubing inserted for removing the leachate. Figure 5.4 shows the plastic tubing that was run to the surface for collection of the leachate into 4-L glass bottles. A vacuum system was used to bring the leachate from the PVC tubes into the bottles.

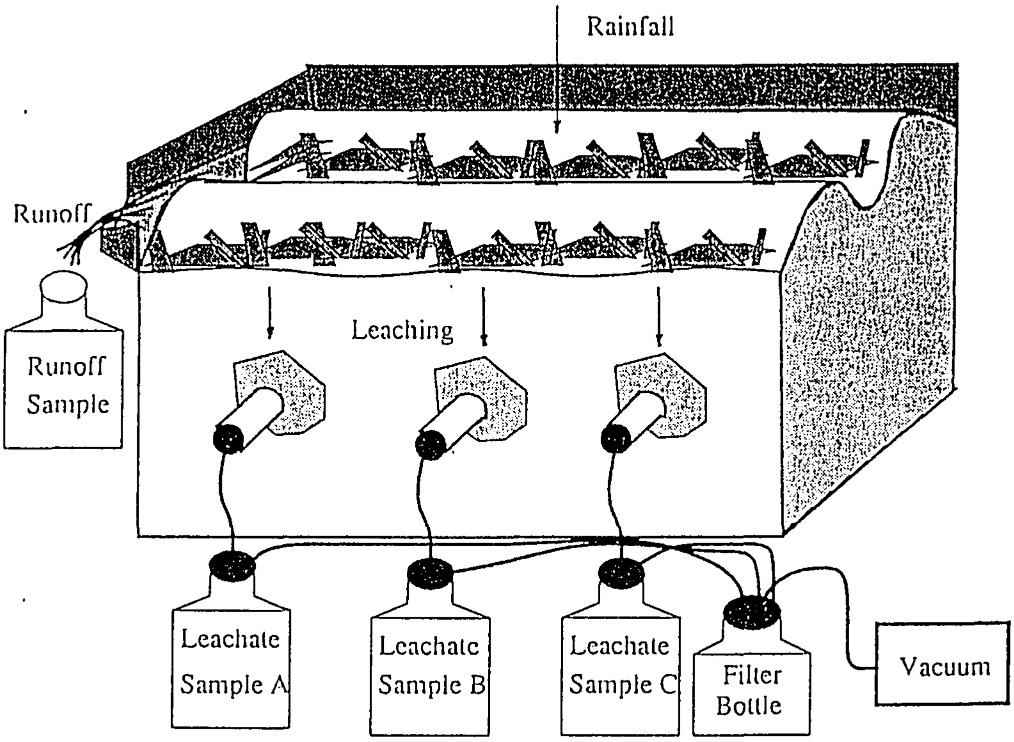

Figure 5.3: Typical plot set up for collecting runoff and leachate

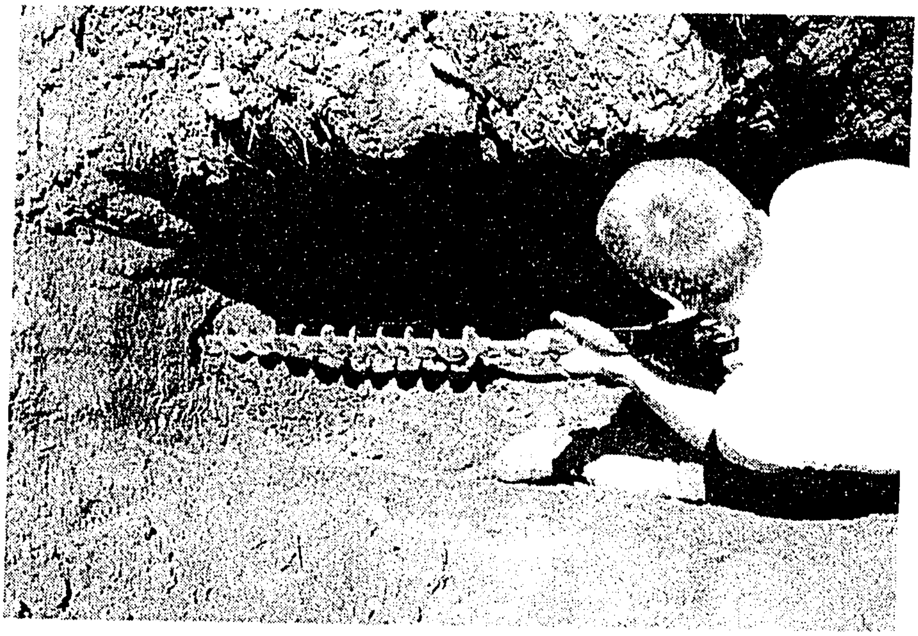

Figure 5.4: Hole being bored for inserting the PVC leaching tubes

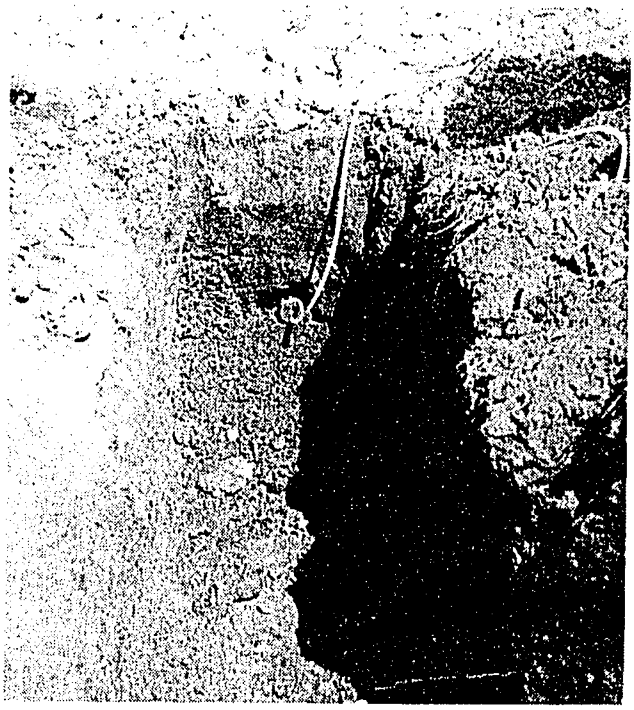

Figure 5.5: Vacuum tube attached to the leaching tube and then run to the surface

Rainfall Simulation and Sample Collection

The runoff plots were subjected to simulated rainfall one to six days after herbicide application with the banding nozzle or the PIC, with surface runoff water and sediment sampled and analyzed for herbicides, similar to previous studies (e.g.,Baker and Laflen, 1979). Before band spraying, four filter papers, double thick, were placed on the surface of each plot to be sprayed and collected immediately after the herbicide application. An average of 3.0, 2.9, and 2.7 kg/ha of propachlor, atrazine, and alachlor were applied to the sprayed plots,respectively. To determine the amount of herbicide that had been applied with the PIC, soil samples at the beginning and the end of each plot were taken after application. The soil samples were taken using a 20 cm x 20 cm square sampler to a depth of 5 cm. This was the same sampler that had been used in the persistence study. Propachlor, atrazine, and alachlor were found to have been applied with the PIC at a rates of 1.4, 1.6, and 1.2 kg/ha, respectively. Soil moisture samples were taken before and after rainfall at depths of 0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm. Four samples were taken within each plot.

Rainfall was applied at a rate of 6.5 cm/h for approximately 1.5 to 2 hours. The rainfall simulator used (Swanson, 1965) approximates the drop-size and energy of natural precipitation. The no-tillage plots were rained on approximately 20 hours after herbicide application, while the other plots were rained on either on the third or sixth day after application. All the plots were covered with plastic sheets within an hour after herbicide application, and this plastic was removed just prior to rainfall. This was done to reduce losses due to volatilization and to keep any natural rainfall off of the plots before simulated rainfall began. A typical setup of the plots and the rainfall simulator is shown in Figure 5.6.

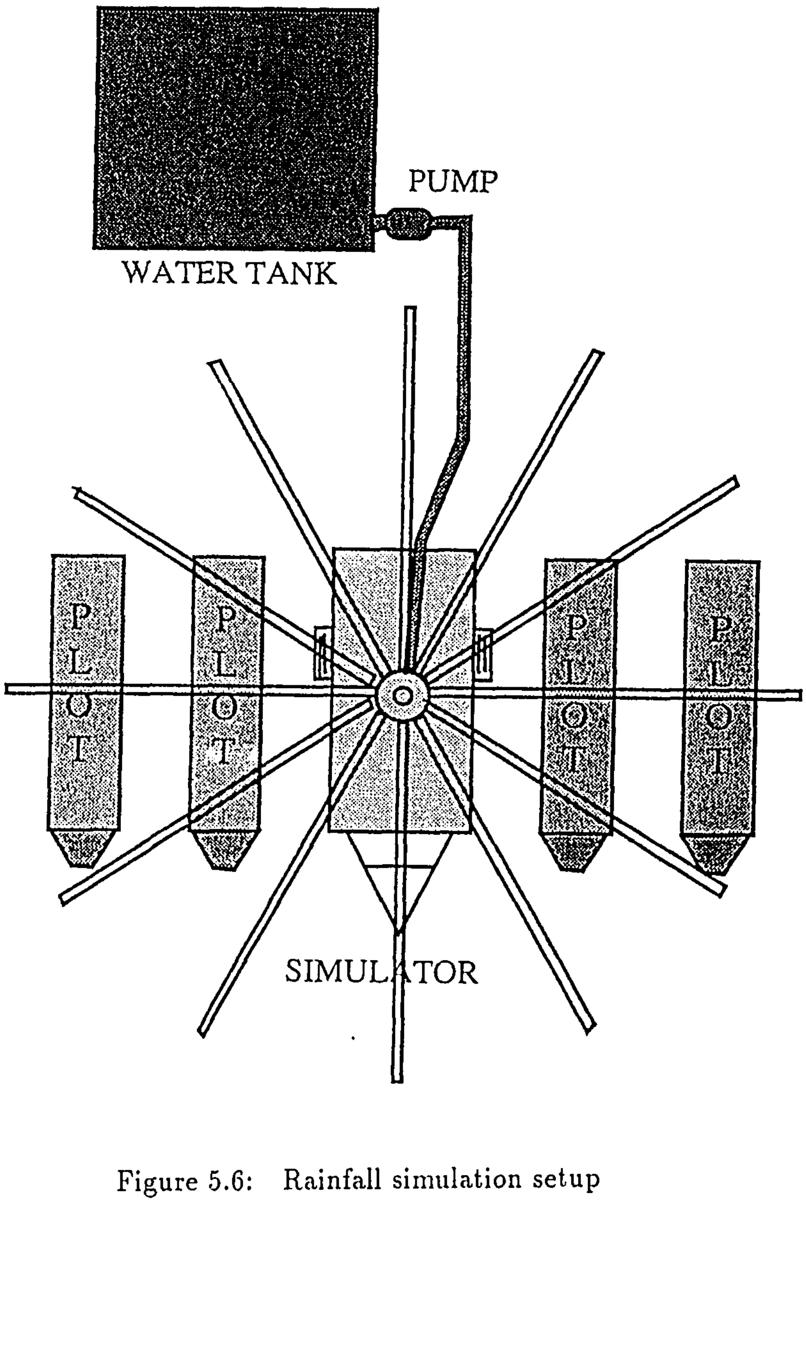

Figure 5.6: Rainfall simulation setup

During the simulated rainfall period, from eight to twelve flow rate measurements were made for each plot during runoff. Four-liter glass bottles were used to collect runoff samples. The first and second four-liter portions of runoff from each plot were used to calculate the first two flow rates, using the time sample collection began (at the beginning of runoff for the first sample; at the end of the first sample for the second sample) and the time to the end of each of these samples. After that, the flow rates were determined gravimetrically by using time-runoff weight measurements. After the second four-liter portion of runoff was collected, flow measurement number three was made.

Runoff samples were collected by periodically passing the mouth of the four-liter glass bottles under the outflow over some time interval. After the first two samples were collected, the third and fourth samples were taken over a five minute period, the fifth sample over a ten minute period, the sixth over a twenty minute period, and the seventh over a thirty minute period. The flow rate measurements were made at the end of the first two five minute periods and thereafter were made at the end of every ten minute period.

The runoff samples were taken immediately to a refrigerated storage room after collection. The following day each sample was shaken with a small portion removed for sediment concentration determinations. The sediment in the runoff samples was then allowed to settle while in a refrigerated space (5°C).

A maximum of three 4-L bottles of leaching water were collected, if possible, during and after the simulated rainfall event. This water was analyzed for the applied herbicides to determine relative leachate concentrations and losses. These samples were also refrigerated until extraction was performed.

The water samples (leaching water and runoff water) were extracted with three portions of the organic solvent, methylene chloride. These water samples were centrifuged prior to extraction to insure that the sediment in the water would not effect the analysis. The methylene chloride extract was then concentrated and redissolved in toluene. The remaining water in the runoff samples was decanted off, leaving the sediment and a small amount of water. These samples were left in the 4-L glass jars for extraction using the organic solvent toluene, with mechanical mixing.

Sample Analysis

The extracts from the water and sediment samples were analyzed using a Tracor 560 gas chromatagraph equipped with a model 702 N-P thermionic detector. The carrier gas was helium with a flow rate of 18 cc/min at a pressure of 276 kPa (40 psi). Reaction gases were hydrogen with a flow rate of 3.5 cc/min at a pressure of 276 kPa and air with a flow rate of 100 cc/min at a pressure of 690 kPa (100 psi). Column oven temperature was held constant at 160^oC with a inlet temperature of 245^oC and a detector temperature of 245^oC. The herbicides were separated using a 3% OV-1 0.63 cm X 1.8 m packed column. Samples were injected into the column using a Tracor 770 auto sampler and detector response was analyzed using a Spectro-Physics 4270 integrator.

Analysis of Data

Runoff volume, sediment loss, and herbicide losses with both sediment and water were calculated for each sample interval from the average of the flow rates and the concentration data; these values were summed over all samples to give total plot losses. Flow-weighted concentrations were calculated by dividing losses with a carrier, either water or sediment, by the volume (or mass) of the carrier for each plot.

FORTRAN programs were written to help analyse the runoff and leaching data. The runoff program was used to calulate the total runoff and erosion, accumulated herbicide losses with both water and sediment, flow weighted concentration for the herbicides in both the runoff water and sediment, and percent herbicide lost in runoff in comparison to that which was applied, on a plot by plot basis. The reported concentration and loss data are the averages for the three replications for each treatment.

The leaching FORTRAN program was developed to estimate the amount of water that would have theoretically have passed through the 45-cm depth, where the leaching tubes were placed under the plots. The program assumed that the only water entering the system was from the rainfall simulator. Flowrate readings were taken at the pump that supplied the water from the water storage tanks to the simulator to calculate the amount of water applied. Rain gauge readings were also available as a check of the average amount of rain water that was applied. Since moisture samples were taken before and after rainfall simulation, it was possible to estimate the amount of water stored in each of three 15-cm thick layers sampled. Gravimetric moisture contents were calculated for every 15-cm of soil, from the soil surface down to the leaching tubes. It was assumed that an average of four such samples for each plot would be representative of the whole plot. Water that did not run off was assumed to be either stored in the soil layers or to have passed through the 45 cm depth. It was also assumed there was no lateral flow. An average bulk density of 1.34 g/cm^3 was obtained from a previous study of the field area, and was used along with the change in moisture content to determine how much rain was stored. The equation used to determine the total drainage volume was the same as that used by Kay (1989)

$$DRV = RAIN - \sum_{i=1}^{3} (SV_i * BD_i * (MW_i - MD_i)/100.0)$$

where:

- DRV = Volume of drainage water, cm^3
- RAIN = Volume of rain water above the plot, cm^3
- SV_i = Soil volume above the leaching tubes in each layer, cm^3
- BD_i = Soil bulk density in each layer, g/cm^3
- MW_i = Gravimetric moisture content of each layer, post-event, %
- MD_i = Gravimetric moisture content of each layer, pre-event, %

Results and Discussion

Figure 5.7 shows the average runoff and erosion losses for the three different tillages for the simulated rainfall events. An average of 10 cm of rainfall was applied to each of the eighteen plots used in this study. The average slope for all the plots was found to be 1.6 percent, as determined by surveying each of the plots. The average time to when runoff began after rainfall was 11, 12, and 31 minutes for the no tillage, ridge tillage, and chisel plow tillage plots, respectively. The chisel plow tillage plots significantly increased the time to runoff when compared to the other two tillage treatments. The chisel plow tillage plots had been chisel plowed and disked just prior to rainfall, increasing roughness or storage areas and infiltration or leaching pathways.

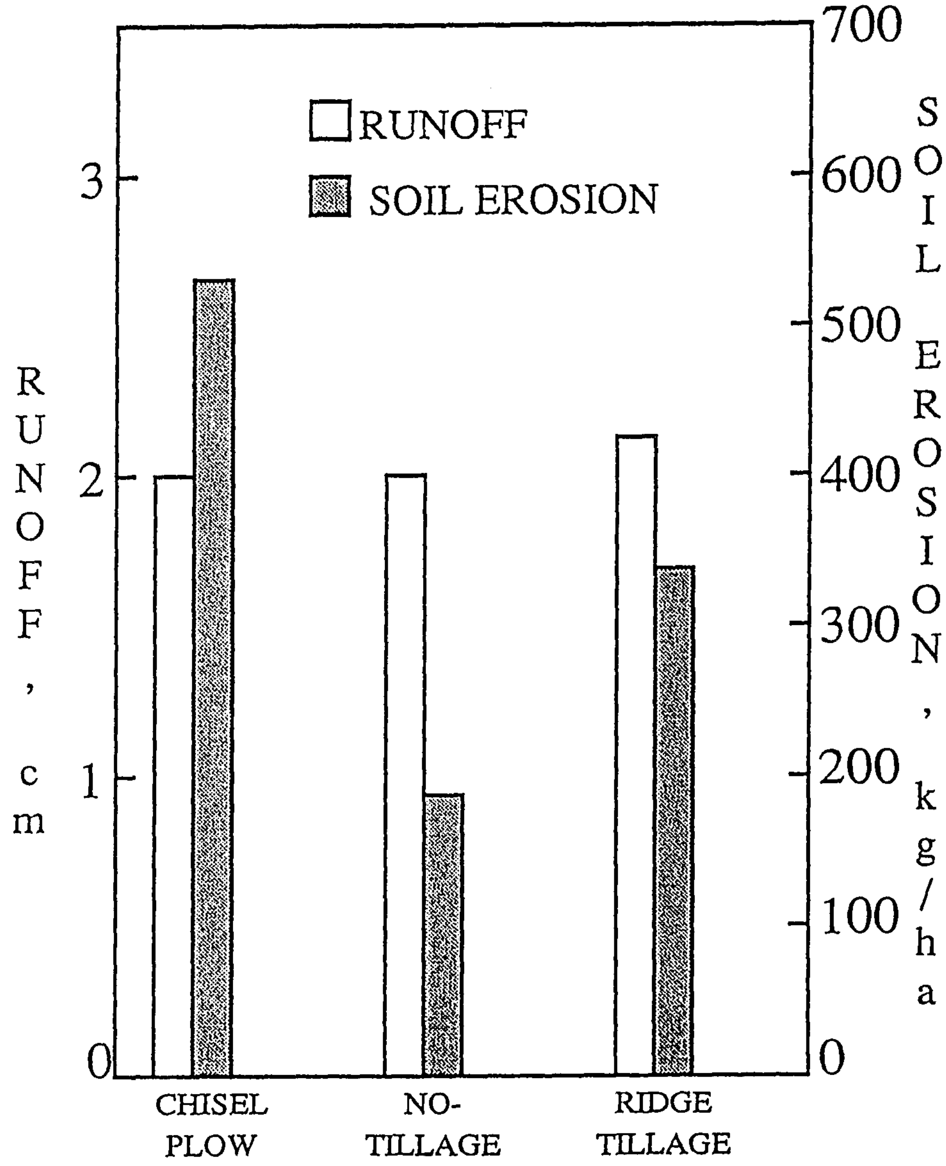

Figure 5.7: Runoff and soil erosion for each tillage treatment

Comparisons of the runoff and erosion losses for each of the tillage treatments was compared on a ratio to rain volume basis to eliminate the differences in rainfall amounts to each plot. No significant difference was found between the runoff amounts from the three tillages treatments. Erosion, although low on these gently sloping plots, was significantly higher for the chisel plow tillage treatments, at the 1% level, when compared to the ridge-tillage and no-tillage plots. A significant difference at the 5% level was also found between the erosion losses between the ridge-tillage and the no-tillage treatments. The loosening of the soil by the chisel plowing, then disking, for the chisel plow tillage treatments buried residue (12% cover) and exposed soil that was easily detached by surface flow and impacting raindrops; thus being carried of by runoff. The no-tillage and the ridge-tillage treatments, with the higher residue covers (65% and 40%, respectively), reduced the soil losses to two-thirds or less of that from the chisel plow tillage treatment with losses of .34 T/ha and .19 T/ha, respectively. The increased residue cover on the ridge-tillage and no-tillage plots apparently decreased soil losses by decreasing rain-drop impact on bare soil and slowing the surface flow.

Table 5.2 shows the rainfall, runoff, soil storage, and estimated leaching amounts for each plot. BI indicates the band-injected plot, while BS indicates the band-sprayed plots. The average percentage of rainfall volume applied passing through the 45-cm depth was calculated to be 16.4, 24.4, and 24.6% for chisel plow tillage (CT), no-tillage (NT), and ridge-tillage (RT), respectively. The average time to when leaching began after rainfall began was 57, 52, and 67 minutes for chisel plow tillage, no-tillage, and ridge-tillage, respectively. The time for leaching to begin for the ridge-tillage plots was significantly longer (10% level) as compared to the other two tillage

Table 5.2: Average rainfall, runoff, soil storage, and leaching amounts treatments.

Treatment	Rep	Rainfall (cm)	Runoff (cm)	Soil Storage (cm)	Leaching (cm)
CT BI	1	10.5	1.9	7.6	1.0
CT BI	2	9.1	2.0	6.7	0.4
CT BI	3	9.4	1.8	7.3	0.3
CT BS	1	10.3	2.0	3.6	4.7
CT BS	2	11.8	2.9	8.0	0.9
CT BS	3	11.6	1.4	6.9	3.3
CT AVERAGE		10.5	2.0	6.7	1.8
NT BI	1	9.8	2.0	7.3	0.5
NT BI	2	10.0	2.3	4.0	3.7
NT BI	3	8.8	1.7	3.0	4.1
NT BS	1	10.0	2.6	6.4	1.0
NT BS	2	8.9	1.7	4.2	3.0
NT BS	3	8.8	2.1	5.5	1.2
NT AVERAGE		9.2	2.0	5.0	2.2
RT BI	1	10.5	2.4	3.7	4.4
RT BI	2	11.8	2.6	6.7	2.5
RT BI	3	11.6	2.5	6.5	2.6
RT BS	1	10.3	1.8	3.9	4.6
RT BS	2	9.1	1.5	6.7	0.9
RT BS	3	9.4	2.0	6.8	0.6
RT AVERAGE		10.5	2.2	5.7	2.6

Figures 5.8, 5.9, and 5.10 show the percentages of alachlor, atrazine, and propachlor lost with runoff water and sediment, and leaching water as compared to the total amount of each chemical applied. Alachlor losses (Figure 5.8) for all treatments was found to be less than 2.5 percent of the alachlor applied. Chisel plow tillage significantly reduced the percent loss of alachlor as compared to the other two tillage methods. Losses of alachlor from the band-injected chisel plow tillage and

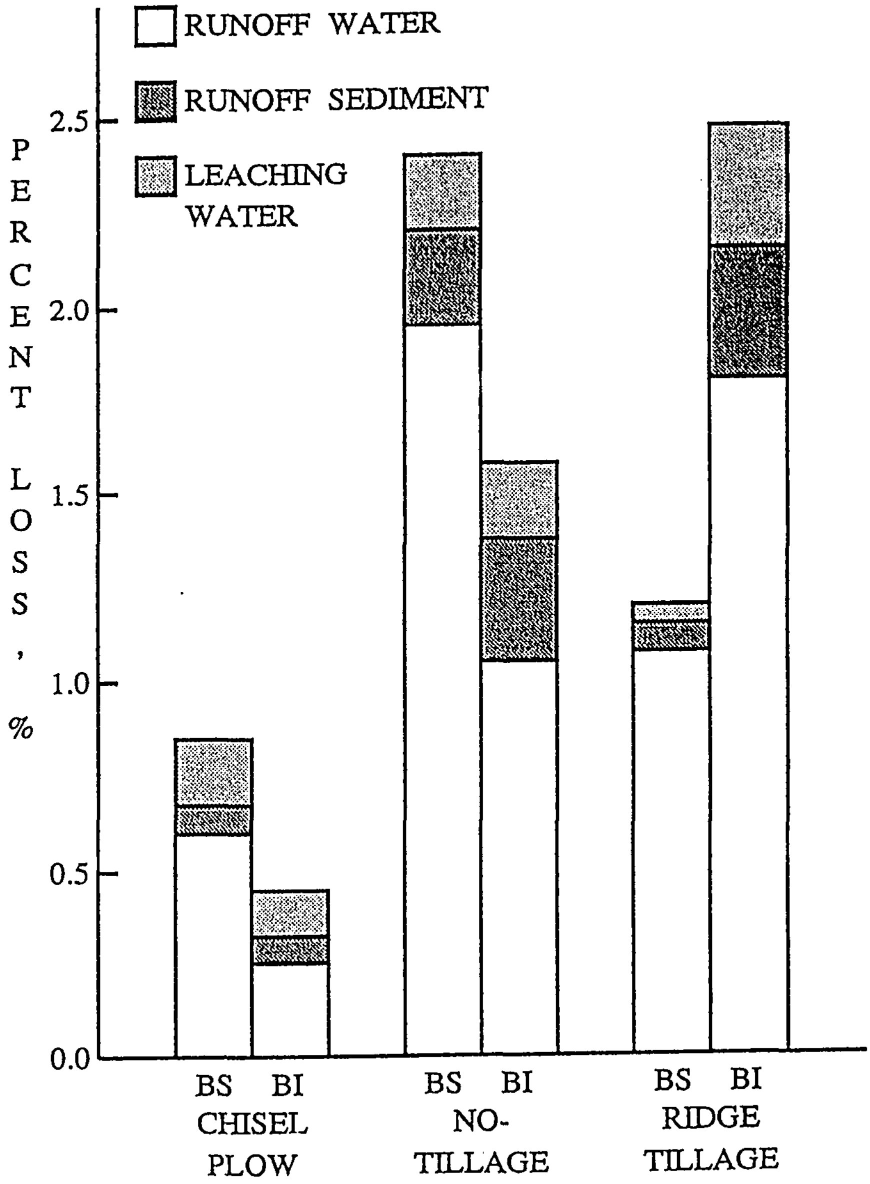

Figure 5.8: Percent of applied alachlor lost with runoff water and sediment, and leaching water

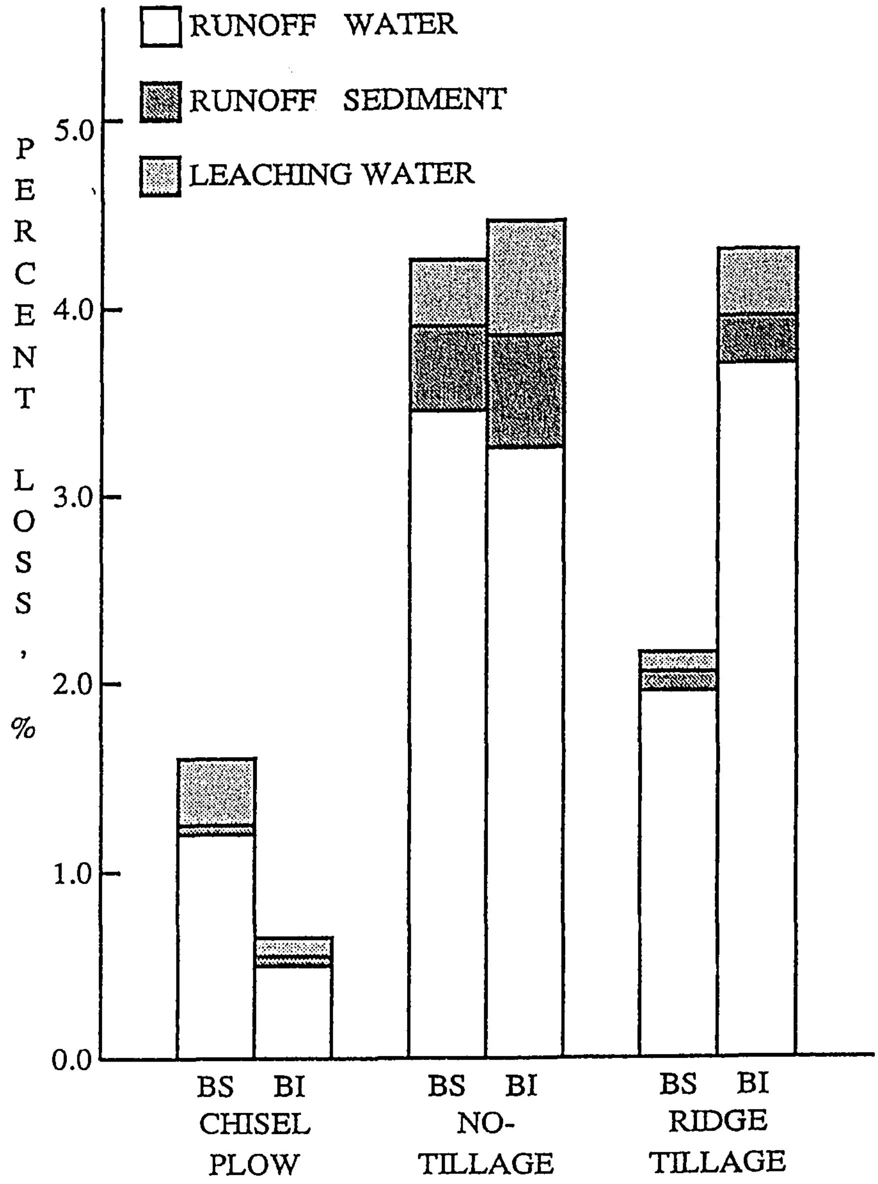

Figure 5.9: Percent of applied atrazine lost with runoff water and sediment, and leaching water

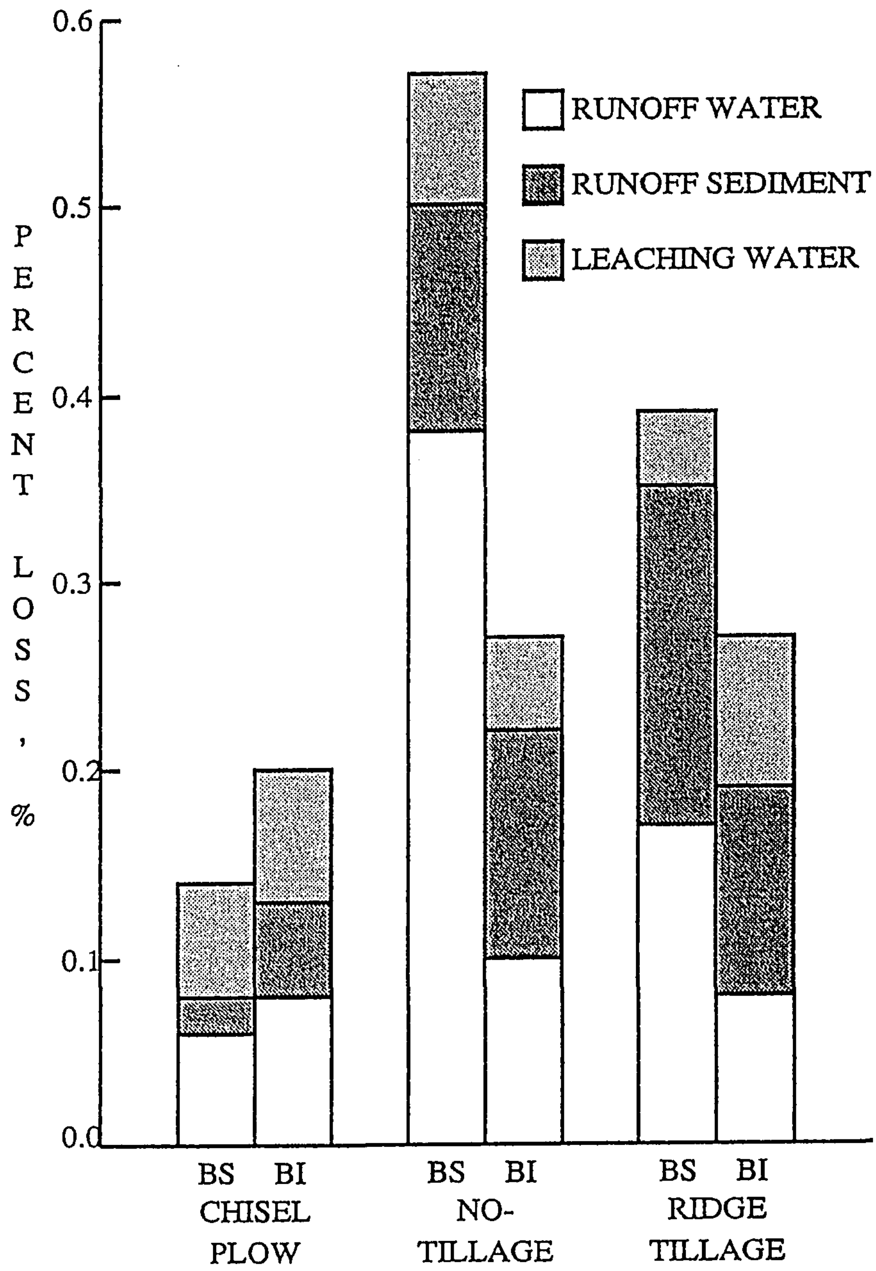

Figure 5.10: Percent of applied propachlor lost with runoff water and sediment, and leaching water

no-tillage plots was lower (although not significantly lower) than those losses from the band-sprayed plots. Total losses from the band-sprayed/ridge-tillage plots was approximately 1/2 of that from the ridge-tillage/band-injected plots. The highest herbicide losses for each treatment occured with the runoff water. Leaching losses for all the treatments was less than 0.5 percent of the alachlor applied.

Atrazine losses, as shown in Figure 5.9, were again lowest for the chisel plow tillage. This can probably be attributed to the longer time period before runoff began on the chisel plow tillage plots. This additional time would allow the soluble atrazine in the top layer of soil to be moved deeper into the soil profile where is would be safe from runoff losses. No significant difference in losses of atrazine when comparing application methods within tillage methods was found. Yet, losses from the band-injected/chisel plot plots were approximately 1/2 of the losses from the band-sprayed/no-tillage plots. The highest losses for all the treatments were found with the band-injected/no-tillage plots, were as much as 5 percent of that applied was lost. It could be that the corn residue kept the injection points from penetrating the soil surface at all times, thus increasing the amount of atrazine left on the soil surface.

Propachlor losses were lower than the losses from atrazine and alachlor, with less than 0.6 percent of that applied being lost with any one treatment. It could be that losses of propachlor due to volatilization and degradation before the simulated rainfall reduced the initial amount present. The highest losses occurred from the band-sprayed/no-tillage plots. Three-fourths of the propachlor lost from these plots was with runoff water. Losses from the band-injected/no-tillage plots was about 1/2 of that from the band-sprayed/no-tillage plots. By placing the propachlor below the residue and into the soil profile, less chemical was lost with runoff water.

Table 5.3 presents the average maximum and minimum herbicide concentrations for the simulated rainfall events. The maximum herbicide concentrations in runoff water typically appeared early after runoff began. Maximum sediment concentration tended to peak more toward the middle of the rainfall event or even at the end, as was discovered for the no-tillage plots. Minimum concentration for the water and sediment for most of the plots occurred late or at the end of the rainfall event. It should be noted again that approximately 1/2 of the amount of herbicide applied to the band-sprayed plots was actually applied to the band-injected plots. This was not intentional. Atrazine water concentrations are approximately 2 to 4 times the alachlor water concentrations, whereas the alachlor water concentrations are approximately 4 to 8 times the water concentrations for propachlor. This is probably due to the differences in the adsorption and solubility properties between the herbicides. The lower maximum and minimum sediment concentration of propachlor for the chisel plow tillage relative to the other tillage treatments could be due to leaching of the propachlor below the zone of interaction with surface flow.

The runoff concentration data as a function of time for both water and sediment were fitted using a non-linear technique and iterative methods that attempt to find the least squares estimates for non-linear models. An equation of the form

$$concentration = Ae^{bt}$$

where A and b are constants, and t is the time after rainfall began was used for both the water and sediment concentration data. An example of the results for this curve fitting method is shown in Figure 5.11. In this example, the decrease in concentration of alachlor over the rainfall period was closely fitted with the non-linear approach for

Table 5.3: Average maximum and minimum water and sediment concentrations

Treatment		Alachlor (ppb) Water	Alachlor (ppb) Sediment	Atrazine (ppb) Water	Atrazine (ppb) Sediment	Propachlor (ppb) Water	Propachlor (ppb) Sediment
CT BI	MAX	40.3	2940	152.4	3560	3.9	2400
CT BI	MIN	2.2	370	14.9	618	0.9	0.0
CT BS	MAX	256	6670	504	3000	60.1	2502
CT BS	MIN	26.6	722	54.7	920	1.1	0.0
NT BI	MAX	50.1	21060	277	45220	3.3	5990
NT BI	MIN	20.4	2016	33.9	2115	2.0	585
NT BS	MAX	213	22940	591	45800	48.6	9994
NT BS	MIN	50.7	5324	70.1	8569	5.5	522
RT BI	MAX	66.2	4263	145	3790	5.5	522
RT BI	MIN	15.6	2545	26.2	1014	0.67	752
RT BS	MAX	121	4550	191	4030	21.7	9560
RT BS	MIN	35.1	1022	51.6	1254	6.5	4514

the chisel plow tillage/band-injected plot ($r^2 = 0.93$ for the atrazine in water and $r^2 = 0.82$ for the atrazine in sediment). Values for A, b, and r^2 were found for each plot (see Appendix F). Values of the constants were similar within replications for most of the treatments when looking at the water concentrations. Atrazine and alachlor concentrations in water for the chisel plow tillage and the ridge-tillage plots over the rainfall period were closely fitted with the non-linear approach in most cases. Propachlor concentrations for all of the treatments could not be fitted with the non-linear equation, and in the majority of the cases, the sediment concentrations fit had low r^2 values. The sediment concentrations, as mention before, did not peak until the middle or even the end of the rainfall period. A bell-shaped curve would possibly give a better fit. Differences in the plot slope, residue cover, tillage, and other variables no doubt are attributed to the variance in the A and b values.

Average concentrations found in the leaching water for each treatment is shown

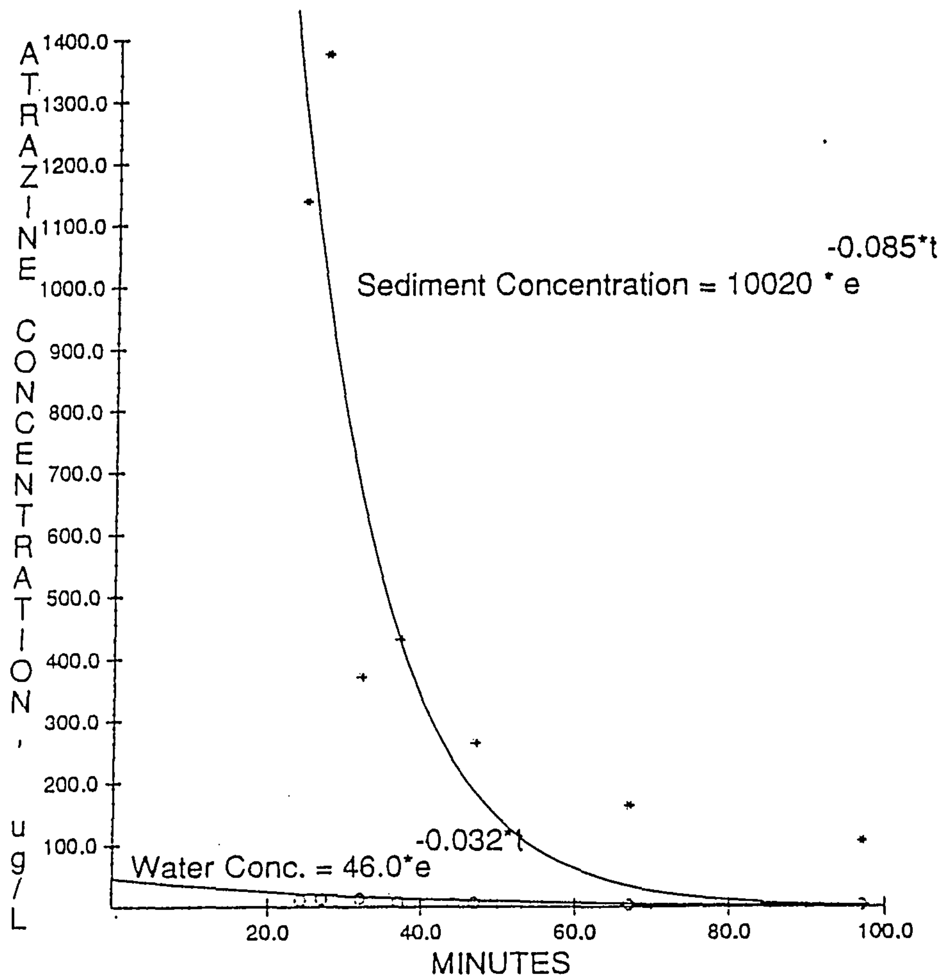

Figure 5.11: Concentration of atrazine in runoff after rainfall began.

Table 5.4: Average concentrations in the leaching water

Treatment	Alachlor ug/l	Atrazine ug/l	Propachlor ug/l
CT BI	26.2	41.5	8.7
CT BS	23.3	50.4	9.0
NT BI	20.8	49.6	5.3
NT BS	25.2	54.1	4.9
RT BI	6.7	11.9	1.8
RT BS	4.4	16.6	2.0

in Table 5.4. Atrazine concentrations ranged from 11.9 to 54.1 ug/l, alachlor concentrations range from 4.4 to 26.2 ug/l, and propachlor concentrations range from 1.8 to 9.0 ug/l. Due to atrazine's persistence and moderate solubility, the high concentration in the leaching water is not surprising. Concentrations for all the ridge-tillage plots were significantly lower that for the other tillage treatments. It was evident during the rainfall events, that some kind of non-uniform macropore flow and lateral flow was taking place. One of the chisel plowtillage plots and one of the ridge-tillage plots had no leaching water that could be sampled during or following the rainfall event, although, the leaching program had predicted that both of these plots would have leaching take place. It is possible that some type of hardened layer in the soil profile was causing the water to flow laterally, instead of straight down to the samplers.

Conclusions

1. Erosion was significantly higher for the chisel plow tillage treatments when compared to the ridge-tillage and no-tillage plots. Erosion losses decreased with increased residue cover on the plots. The soil losses increased in order of no-tillage < ridge-tillage < chisel plow tillage.

2. Runoff volumes were all about 20% of the of rainfall volume applied. No significant difference was found between tillage methods.

3. No significant difference was found in the runoff water and sediment, or the leaching water losses for atrazine, alachlor, or propachlor when applied by either the point injector or a band spraying nozzle for the ridge tillage, chisel plow tillage, and no tillage plots.

4. Total herbicide losses (runoff water + runoff sediment + leaching water) for all the treatments were found to be less than 5% of that amount of hericide that had been applied. Atrazine losses from the no-tillage plots were as high as 5%; alachlor losses from the no-tillage and ridge-tillage plots were as high as 2.5% of that applied; and propachlor losses from the no-tillage plots were as high as .5% of that applied.

5. There was no clear evidence that the PIC would significantly reduce the losses to runoff and leaching when compared to band spraying.

6. Herbicide concentrations in leaching water for all the ridge tillage plots were significantly lower than those concentrations found with the no-tillage and chisel plow plots.

7. The decrease in concentraton of the herbicides atrazine and alachlor in water over the rainfall period was closely fitted by using a non-linear curve fitting approach with an equation of the form:

$$Concentration = Ae^{b}t$$

where A and b are constants, and t is the time after rainfall began.

CHAPTER 6. GENERAL SUMMARY

Results

Successful completion of this project has resulted in the development and evaluation of an alternative method of banding herbicides (or insecticides) that significantly reduces problems in three areas.

First, direct contact of the wheel applicator with the soil avoids the potential atmospheric losses that can occur with spraying. This is a particular problem in the spring when time is short and herbicide application is combined with planting. Conditions may be appropriate for planting, but not for spraying because of the wind.

Second, volatilization losses are potentially greater for herbicides applied to crop residue with conservation tillage because of less interaction with the residue than soil (i.e. adsorption). Avoiding direct application to crop residue through injection through the residue, or use of strip tillage for application to bare soil eliminates this increased potential volatilization. It is quite likely that atmospheric losses will receive more attention in the future as another avenue for human and environmental pesticide exposure, and it is certainly desirable to be able to continue to promote conservation tillage without fear of causing another problem at the expense of solving the erosion problem.

And third, it is known that soil incorporation reduces surface runoff losses, photodegradation, and volatilization of herbicides just as well as surface application without incorporation. The wheel applicator provides an easy means to incorporate herbicides without the power, energy, and residue destruction required with tillage incorporation. Although recent emphasis has been placed on ground water contamination concerns, it is known that more pesticide is lost with surface runoff on a percent-applied basis. In addition, through alluvial systems, sink-holes, etc., there is interchange between ground water and surface water, hence surface runoff losses of pesticides are also a concern.

The wheel applicator represents an innovative approach to improving application technology. Improvements in the use and placement of these chemical tools are needed. Chemical tools, in the way of herbicide use, are an important part of crop production in the North Central Region with approximately 66 percent of the crop land treated with herbicides in 1978 (Waldron and Park, 1981). A more recent survey shows that 97 percent of the row-crop land in Iowa was treated with herbicides in 1985 (Wintersteen and Hartzler, 1987). The three herbicides chosen for this study, alachlor, atrazine, and propachlor represent heavily used herbicides in the region. In addition, alachlor is considered a probable human carcinogen (class B) and atrazine a possible human carcinogen (class C).

Recommendations for Future Work

The point injection system has been found to be an effective tool in applying herbicide both on bare surfaces and surfaces covered with heavy crop residue. Potential uses of this point injection technology could easily move outside just the uses with herbicides. One potential use could be for application of liquid nutrients at the time of planting. The injector would place the nutrients in the zone of the most potential use by the young growing plants, and would reduce losses between the rows of the crops. Other uses might include liquid injection of insecticides. Recently, concern has been increased on placing granular insecticide on the surface where animals have easy access to them. The band injector once again could be effective in incorporating the insecticides below the soil surface where it could still control the insect problem. Work would have to be done on how to apply the insecticides so that the farmer would have minimum contact with the insecticide. Others have shown an interest in using the band injector with crops, besides just corn and soybean. The band injector could be designed to apply nutrients to forage crops or maybe even for application of lawn fertilizers and chemicals. The future of this kind of applicator seems to be bright in a world where the concerns for proper chemical application tend to increase every day. Engineers and researchers can not ignore environmentalist and other concerned groups any longer.

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APPENDIX A. GROWTH CHAMBER DATA

Table A.1: Point injection growth chamber study data

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
CK	D1	V1	R1	C1	7.5	2.5	0.0	0.0	0.0
CK	D1	V1	R1	C2	5.0	7.5	0.0	5.0	2.5
CK	D1	V1	R1	C3	2.5	5.0	5.0	2.5	0.0
CK	D1	V1	R1	C4	2.5	0.0	5.0	0.0	7.5
CK	D1	V1	R1	C5	10.0	0.0	0.0	2.5	0.0
CK	D1	V1	R1	C6	0.0	0.0	0.0	0.0	0.0
BL	D1	V1	R1	C1	0.0	0.0	0.0	0.0	0.0
BL	D1	V1	R1	C2	0.0	0.0	0.0	0.0	0.0
BL	D1	V1	R1	C3	0.0	0.0	0.0	0.0	0.0
BL	D1	V1	R1	C4	0.0	0.0	0.0	0.0	0.0
BL	D1	V1	R1	C5	0.0	0.0	0.0	0.0	0.0
BL	D1	V1	R1	C6	10.0	0.0	0.0	0.0	0.0
LA	D1	V1	R1	C1	0.0	0.0	0.0	0.0	0.0
LA	D1	V1	R1	C2	10.0	0.0	0.0	0.0	0.0
LA	D1	V1	R1	C3	0.0	0.0	0.0	0.0	0.0
LA	D1	V1	R1	C4	0.0	0.0	0.0	0.0	0.0
LA	D1	V1	R1	C5	0.0	0.0	0.0	0.0	0.0
LA	D1	V1	R1	C6	0.0	10.0	10.0	10.0	0.0
CK	D1	V1	R2	C1	0.0	7.5	5.0	2.5	7.5
CK	D1	V1	R2	C2	2.5	7.5	0.0	0.0	0.0
CK	D1	V1	R2	C3	0.0	0.0	0.0	2.5	2.5
CK	D1	V1	R2	C4	10.0	0.0	0.0	5.0	0.0
CK	D1	V1	R2	C5	2.5	0.0	5.0	0.0	0.0
CK	D1	V1	R2	C6	7.5	0.0	0.0	0.0	0.0
BL	D1	V1	R2	C1	0.0	7.5	2.5	0.0	5.0
BL	D1	V1	R2	C2	5.0	5.0	2.5	0.0	0.0
BL	D1	V1	R2	C3	5.0	5.0	0.0	0.0	0.0
BL	D1	V1	R2	C4	10.0	5.0	5.0	5.0	0.0
BL	D1	V1	R2	C5	7.5	7.5	2.5	0.0	0.0
BL	D1	V1	R2	C6	10.0	7.5	5.0	2.5	0.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor

[b] D1=1 cm, D2 = 2 cm

[c] V1=187 L/ha, V2=748 L/ha

Table A.2: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
LA	D1	V1	R2	C1	10.0	0.0	0.0	10.0	0.0
LA	D1	V1	R2	C2	7.5	0.0	5.0	0.0	0.0
LA	D1	V1	R2	C3	10.0	5.0	5.0	10.0	0.0
LA	D1	V1	R2	C4	5.0	5.0	7.5	0.0	0.0
LA	D1	V1	R2	C5	7.5	7.5	2.5	0.0	5.0
LA	D1	V1	R2	C6	7.5	7.5	10.0	10.0	10.0
CK	D1	V1	R3	C1	7.5	5.0	0.0	2.5	2.5
CK	D1	V1	R3	C2	5.0	2.5	0.0	0.0	0.0
CK	D1	V1	R3	C3	7.5	5.0	2.5	2.5	2.5
CK	D1	V1	R3	C4	2.5	2.5	5.0	10.0	0.0
CK	D1	V1	R3	C5	0.0	7.5	0.0	0.0	0.0
CK	D1	V1	R3	C6	10.0	2.5	2.5	0.0	2.5
BL	D1	V1	R3	C1	7.5	0.0	7.5	0.0	0.0
BL	D1	V1	R3	C2	7.5	5.0	5.0	5.0	2.5
BL	D1	V1	R3	C3	5.0	5.0	10.0	7.5	5.0
BL	D1	V1	R3	C4	5.0	10.0	10.0	5.0	7.5
BL	D1	V1	R3	C5	2.5	5.0	0.0	0.0	0.0
BL	D1	V1	R3	C6	5.0	2.5	2.5	0.0	5.0
LA	D1	V1	R3	C1	7.5	2.5	5.0	0.0	0.0
LA	D1	V1	R3	C2	10.0	7.5	5.0	0.0	0.0
LA	D1	V1	R3	C3	10.0	7.5	10.0	0.0	0.0
LA	D1	V1	R3	C4	7.5	10.0	0.0	0.0	0.0
LA	D1	V1	R3	C5	7.5	7.5	5.0	0.0	0.0
LA	D1	V1	R3	C6	10.0	10.0	0.0	5.0	0.0
CK	D1	V1	R4	C1	0.0	2.5	2.5	5.0	2.5
CK	D1	V1	R4	C2	2.5	5.0	0.0	0.0	2.5
CK	D1	V1	R4	C3	7.5	5.0	0.0	7.5	0.0
CK	D1	V1	R4	C4	5.0	5.0	5.0	0.0	0.0
CK	D1	V1	R4	C5	5.0	2.5	2.5	2.5	5.0
CK	D1	V1	R4	C6	2.5	0.0	5.0	5.0	5.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor
[b] D1=1 cm, D2 = 2 cm
[c] V1=187 L/ha, V2=748 L/ha

Table A.3: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
BL	D1	V1	R4	C1	10.0	2.5	2.5	0.0	2.5
BL	D1	V1	R4	C2	5.0	7.5	2.5	0.0	5.0
BL	D1	V1	R4	C3	7.5	2.5	5.0	2.5	0.0
BL	D1	V1	R4	C4	10.0	5.0	5.0	0.0	10.0
BL	D1	V1	R4	C5	10.0	7.5	5.0	2.5	0.0
BL	D1	V1	R4	C6	7.5	10.0	5.0	2.5	0.0
LA	D1	V1	R4	C1	7.5	0.0	0.0	0.0	10.0
LA	D1	V1	R4	C2	7.5	5.0	0.0	2.5	0.0
LA	D1	V1	R1	C3	10.0	5.0	7.5	7.5	0.0
LA	D1	V1	R1	C4	10.0	5.0	0.0	0.0	0.0
LA	D1	V1	R1	C5	7.5	5.0	5.0	2.5	5.0
LA	D1	V1	R1	C6	5.0	5.0	2.5	2.5	0.0
CK	D1	V2	R1	C1	10.0	5.0	10.0	10.0	7.5
CK	D1	V2	R1	C2	5.0	5.0	5.0	0.0	2.5
CK	D1	V2	R1	C3	7.5	7.5	7.5	5.0	5.0
CK	D1	V2	R1	C4	5.0	7.5	7.5	5.0	2.5
CK	D1	V2	R1	C5	10.0	5.0	0.0	10.0	2.5
CK	D1	V2	R1	C6	2.5	0.0	5.0	5.0	2.5
BL	D1	V2	R1	C1	10.0	10.0	10.0	0.0	10.0
BL	D1	V2	R1	C2	10.0	10.0	10.0	2.5	2.5
BL	D1	V2	R1	C3	10.0	5.0	2.5	5.0	0.0
BL	D1	V2	R1	C4	10.0	10.0	2.5	2.5	5.0
BL	D1	V2	R1	C5	5.0	2.5	7.5	2.5	5.0
BL	D1	V2	R1	C6	10.0	2.5	5.0	2.5	2.5
LA	D1	V2	R1	C1	5.0	2.5	2.5	5.0	0.0
LA	D1	V2	R1	C2	10.0	5.0	5.0	7.5	5.0
LA	D1	V2	R1	C3	0.0	5.0	5.0	0.0	0.0
LA	D1	V2	R1	C4	2.5	7.5	10.0	2.5	2.5
LA	D1	V2	R1	C5	2.5	7.5	7.5	10.0	2.5
LA	D1	V2	R1	C6	0.0	5.0	0.0	0.0	5.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor

[b] D1=1 cm, D2 = 2 cm

[c] V1=187 L/ha, V2=748 L/ha

Table A.4: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
CK	D1	V2	R2	C1	0.0	0.0	10.0	10.0	2.5
CK	D1	V2	R2	C2	10.0	10.0	5.0	2.5	2.5
CK	D1	V2	R2	C3	5.0	10.0	2.5	0.0	7.5
CK	D1	V2	R2	C4	5.0	5.0	2.5	2.5	2.5
CK	D1	V2	R2	C5	2.5	10.0	5.0	10.0	7.5
CK	D1	V2	R2	C6	10.0	0.0	2.5	2.5	2.5
BL	D1	V2	R2	C1	7.5	10.0	0.0	0.0	0.0
BL	D1	V2	R2	C2	5.0	0.0	7.5	2.5	2.5
BL	D1	V2	R2	C3	7.5	10.0	10.0	0.0	0.0
BL	D1	V2	R2	C4	7.5	10.0	0.0	0.0	5.0
BL	D1	V2	R2	C5	7.5	7.5	0.0	0.0	0.0
BL	D1	V2	R2	C6	7.5	0.0	10.0	7.5	0.0
LA	D1	V2	R2	C1	2.5	0.0	0.0	5.0	7.5
LA	D1	V2	R2	C2	2.5	10.0	2.5	0.0	10.0
LA	D1	V2	R2	C3	5.0	2.5	10.0	0.0	0.0
LA	D1	V2	R2	C4	7.5	2.5	5.0	0.0	0.0
LA	D1	V2	R2	C5	5.0	5.0	0.0	0.0	2.5
LA	D1	V2	R2	C6	5.0	0.0	10.0	0.0	0.0
CK	D1	V2	R3	C1	2.5	2.5	2.5	0.0	0.0
CK	D1	V2	R3	C2	7.5	0.0	0.0	0.0	0.0
CK	D1	V2	R3	C3	2.5	0.0	2.5	2.5	0.0
CK	D1	V2	R3	C4	2.5	2.5	0.0	5.0	2.5
CK	D1	V2	R3	C5	10.0	2.5	2.5	0.0	7.5
CK	D1	V2	R3	C6	10.0	10.0	2.5	2.5	0.0
BL	D1	V2	R3	C1	10.0	5.0	7.5	10.0	10.0
BL	D1	V2	R3	C2	10.0	0.0	0.0	0.0	0.0
BL	D1	V2	R3	C3	10.0	5.0	2.5	7.5	5.0
BL	D1	V2	R3	C4	10.0	7.5	0.0	2.5	0.0
BL	D1	V2	R3	C5	10.0	10.0	7.5	5.0	5.0
BL	D1	V2	R3	C6	2.5	2.5	0.0	0.0	0.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor
[b] D1=1 cm, D2 = 2 cm
[c] V1=187 L/ha, V2=748 L/ha

Table A.5: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
LA	D1	V2	R3	C1	10.0	2.5	2.5	5.0	0.0
LA	D1	V2	R3	C2	7.5	2.5	0.0	0.0	0.0
LA	D1	V2	R3	C3	5.0	7.5	0.0	0.0	2.5
LA	D1	V2	R3	C4	10.0	2.5	7.5	0.0	0.0
LA	D1	V2	R3	C5	7.5	0.0	7.5	0.0	0.0
LA	D1	V2	R3	C6	2.5	0.0	2.5	0.0	5.0
CK	D1	V2	R4	C1	7.5	2.5	10.0	5.0	0.0
CK	D1	V2	R4	C2	0.0	0.0	5.0	5.0	2.5
CK	D1	V2	R4	C3	5.0	2.5	0.0	0.0	0.0
CK	D1	V2	R4	C4	10.0	5.0	5.0	10.0	0.0
CK	D1	V2	R4	C5	5.0	5.0	5.0	2.5	0.0
CK	D1	V2	R4	C6	7.5	0.0	2.5	2.5	0.0
BL	D1	V2	R4	C1	2.5	10.0	0.0	0.0	2.5
BL	D1	V2	R4	C2	10.0	0.0	5.0	0.0	2.5
BL	D1	V2	R4	C3	5.0	0.0	0.0	2.5	7.5
BL	D1	V2	R4	C4	5.0	5.0	5.0	5.0	10.0
BL	D1	V2	R4	C5	5.0	5.0	0.0	2.5	2.5
BL	D1	V2	R4	C6	10.0	0.0	0.0	0.0	0.0
LA	D1	V2	R4	C1	2.5	2.5	0.0	5.0	2.5
LA	D1	V2	R4	C2	5.0	2.5	0.0	7.5	5.0
LA	D1	V2	R4	C3	2.5	5.0	7.5	5.0	5.0
LA	D1	V2	R4	C4	5.0	7.5	0.0	2.5	5.0
LA	D1	V2	R4	C5	7.5	7.5	0.0	5.0	2.5
LA	D1	V2	R4	C6	7.5	0.0	7.5	2.5	2.5
CK	D2	V1	R1	C1	10.0	10.0	10.0	0.0	7.5
CK	D2	V1	R1	C2	10.0	10.0	0.0	5.0	10.0
CK	D2	V1	R1	C3	2.5	2.5	2.5	0.0	2.5
CK	D2	V1	R1	C4	10.0	5.0	5.0	7.5	2.5
CK	D2	V1	R1	C5	0.0	2.5	2.5	2.5	5.0
CK	D2	V1	R1	C6	7.5	0.0	2.5	5.0	5.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor

[b] D1=1 cm, D2 = 2 cm

[c] V1=187 L/ha, V2=748 L/ha

Table A.6: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
BL	D2	V1	R1	C1	2.5	5.0	10.0	5.0	2.5
BL	D2	V1	R1	C2	10.0	0.0	5.0	5.0	2.5
BL	D2	V1	R1	C3	7.5	7.5	5.0	5.0	0.0
BL	D2	V1	R1	C4	7.5	10.0	5.0	2.5	5.0
BL	D2	V1	R1	C5	7.5	5.0	2.5	0.0	0.0
BL	D2	V1	R1	C6	10.0	5.0	5.0	5.0	7.5
LA	D2	V1	R1	C1	5.0	0.0	0.0	2.5	2.5
LA	D2	V1	R1	C2	7.5	5.0	2.5	2.5	5.0
LA	D2	V1	R1	C3	7.5	0.0	10.0	0.0	0.0
LA	D2	V1	R1	C4	2.5	5.0	5.0	2.5	0.0
LA	D2	V1	R1	C5	10.0	10.0	0.0	0.0	0.0
LA	D2	V1	R1	C6	7.5	5.0	5.0	10.0	10.0
CK	D2	V1	R2	C1	10.0	5.0	0.0	7.5	2.5
CK	D2	V1	R2	C2	0.0	2.5	0.0	2.5	0.0
CK	D2	V1	R2	C3	2.5	7.5	5.0	10.0	10.0
CK	D2	V1	R2	C4	2.5	7.5	2.5	0.0	2.5
CK	D2	V1	R2	C5	5.0	5.0	5.0	7.5	0.0
CK	D2	V1	R2	C6	2.5	10.0	10.0	2.5	5.0
BL	D2	V1	R2	C1	10.0	0.0	5.0	7.5	2.5
BL	D2	V1	R2	C2	10.0	0.0	0.0	0.0	0.0
BL	D2	V1	R2	C3	5.0	7.5	0.0	0.0	0.0
BL	D2	V1	R2	C4	5.0	10.0	5.0	0.0	0.0
BL	D2	V1	R2	C5	10.0	0.0	0.0	0.0	5.0
BL	D2	V1	R2	C6	10.0	10.0	10.0	10.0	0.0
LA	D2	V1	R2	C1	0.0	0.0	0.0	0.0	5.0
LA	D2	V1	R2	C2	5.0	0.0	5.0	0.0	0.0
LA	D2	V1	R2	C3	7.5	5.0	0.0	7.5	5.0
LA	D2	V1	R2	C4	7.5	10.0	0.0	10.0	0.0
LA	D2	V1	R2	C5	10.0	7.5	5.0	0.0	2.5
LA	D2	V1	R2	C6	10.0	10.0	10.0	5.0	2.5

[a] CK=Check, BL=Cyanazine, LA=Alachlor
[b] D1=1 cm, D2 = 2 cm
[c] V1=187 L/ha, V2=748 L/ha

Table A.7: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
CK	D2	V1	R3	C1	0.0	7.5	2.5	10.0	7.5
CK	D2	V1	R3	C2	5.0	5.0	5.0	0.0	0.0
CK	D2	V1	R3	C3	5.0	0.0	5.0	5.0	2.5
CK	D2	V1	R3	C4	10.0	2.5	0.0	10.0	2.5
CK	D2	V1	R3	C5	0.0	10.0	5.0	0.0	0.0
CK	D2	V1	R3	C6	10.0	0.0	0.0	0.0	0.0
BL	D2	V1	R3	C1	5.0	0.0	0.0	2.5	5.0
BL	D2	V1	R3	C2	10.0	0.0	5.0	0.0	0.0
BL	D2	V1	R3	C3	2.5	2.5	7.5	5.0	5.0
BL	D2	V1	R3	C4	10.0	0.0	7.5	7.5	7.5
BL	D2	V1	R3	C5	10.0	0.0	5.0	0.0	0.0
BL	D2	V1	R3	C6	10.0	2.5	0.0	7.5	2.5
LA	D2	V1	R3	C1	2.5	7.5	2.5	7.5	5.0
LA	D2	V1	R3	C2	7.5	5.0	5.0	7.5	0.0
LA	D2	V1	R3	C3	5.0	7.5	2.5	2.5	0.0
LA	D2	V1	R3	C4	7.5	5.0	2.5	0.0	2.5
LA	D2	V1	R3	C5	2.5	5.0	2.5	10.0	10.0
LA	D2	V1	R3	C6	2.5	10.0	5.0	0.0	5.0
CK	D2	V1	R4	C1	5.0	5.0	7.5	10.0	10.0
CK	D2	V1	R4	C2	5.0	2.5	2.5	5.0	5.0
CK	D2	V1	R4	C3	5.0	7.5	5.0	7.5	7.5
CK	D2	V1	R4	C4	5.0	10.0	7.5	5.0	5.0
CK	D2	V1	R4	C5	7.5	10.0	5.0	7.5	7.5
CK	D2	V1	R4	C6	10.0	5.0	7.5	0.0	2.5
BL	D2	V1	R4	C1	10.0	10.0	2.5	5.0	5.0
BL	D2	V1	R4	C2	10.0	0.0	10.0	5.0	2.5
BL	D2	V1	R4	C3	10.0	10.0	10.0	5.0	0.0
BL	D2	V1	R4	C4	7.5	7.5	7.5	5.0	7.5
BL	D2	V1	R4	C5	5.0	5.0	5.0	7.5	5.0
BL	D2	V1	R4	C6	10.0	2.5	0.0	0.0	0.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor

[b] D1=1 cm, D2 = 2 cm

[c] V1=187 L/ha, V2=748 L/ha

Table A.8: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
LA	D2	V1	R4	C1	10.0	2.5	5.0	10.0	10.0
LA	D2	V1	R4	C2	5.0	0.0	5.0	10.0	5.0
LA	D2	V1	R4	C3	7.5	2.5	2.5	5.0	7.5
LA	D2	V1	R4	C4	10.0	10.0	0.0	0.0	0.0
LA	D2	V1	R4	C5	10.0	10.0	2.5	10.0	10.0
LA	D2	V1	R4	C6	7.5	7.5	7.5	5.0	2.5
CK	D2	V2	R1	C1	10.0	5.0	10.0	7.5	7.5
CK	D2	V2	R1	C2	0.0	10.0	2.5	0.0	0.0
CK	D2	V2	R1	C3	7.5	0.0	10.0	5.0	0.0
CK	D2	V2	R1	C4	0.0	10.0	10.0	2.5	0.0
CK	D2	V2	R1	C5	0.0	0.0	0.0	2.5	0.0
CK	D2	V2	R1	C6	10.0	7.5	5.0	2.5	2.5
BL	D2	V2	R1	C1	2.5	10.0	0.0	5.0	5.0
BL	D2	V2	R1	C2	10.0	5.0	2.5	5.0	0.0
BL	D2	V2	R1	C3	10.0	5.0	5.0	5.0	0.0
BL	D2	V2	R1	C4	5.0	2.5	2.5	0.0	0.0
BL	D2	V2	R1	C5	10.0	7.5	2.5	0.0	5.0
BL	D2	V2	R1	C6	10.0	0.0	0.0	0.0	2.5
LA	D2	V2	R1	C1	5.0	2.5	0.0	0.0	10.0
LA	D2	V2	R1	C2	5.0	5.0	0.0	0.0	0.0
LA	D2	V2	R1	C3	7.5	0.0	7.5	2.5	0.0
LA	D2	V2	R1	C4	2.5	0.0	0.0	0.0	0.0
LA	D2	V2	R1	C5	10.0	5.0	0.0	0.0	0.0
LA	D2	V2	R1	C6	5.0	5.0	10.0	5.0	5.0
CK	D2	V2	R2	C1	0.0	2.5	2.5	0.0	0.0
CK	D2	V2	R2	C2	7.5	5.0	0.0	10.0	0.0
CK	D2	V2	R2	C3	10.0	10.0	10.0	2.5	0.0
CK	D2	V2	R2	C4	10.0	0.0	0.0	0.0	0.0
CK	D2	V2	R2	C5	5.0	0.0	5.0	7.5	2.5
CK	D2	V2	R2	C6	7.5	0.0	0.0	0.0	5.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor
[b] D1=1 cm, D2 = 2 cm
[c] V1=187 L/ha, V2=748 L/ha

Table A.9: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
BL	D2	V2	R2	C1	10.0	0.0	7.5	2.5	0.0
BL	D2	V2	R2	C2	10.0	0.0	5.0	0.0	0.0
BL	D2	V2	R2	C3	0.0	0.0	0.0	2.5	2.5
BL	D2	V2	R2	C4	5.0	0.0	5.0	5.0	2.5
BL	D2	V2	R2	C5	7.5	7.5	10.0	0.0	0.0
BL	D2	V2	R2	C6	10.0	0.0	0.0	0.0	10.0
LA	D2	V2	R2	C1	5.0	5.0	0.0	10.0	0.0
LA	D2	V2	R2	C2	7.5	5.0	10.0	10.0	0.0
LA	D2	V2	R2	C3	10.0	7.5	0.0	2.5	0.0
LA	D2	V2	R2	C4	0.0	0.0	0.0	10.0	7.5
LA	D2	V2	R2	C5	7.5	7.5	0.0	2.5	0.0
LA	D2	V2	R2	C6	10.0	2.5	0.0	2.5	0.0
CK	D2	V2	R3	C1	5.0	10.0	10.0	5.0	2.5
CK	D2	V2	R3	C2	10.0	0.0	0.0	0.0	10.0
CK	D2	V2	R3	C3	0.0	7.5	0.0	0.0	0.0
CK	D2	V2	R3	C4	0.0	2.5	2.5	5.0	0.0
CK	D2	V2	R3	C5	0.0	5.0	2.5	0.0	0.0
CK	D2	V2	R3	C6	0.0	0.0	0.0	5.0	0.0
BL	D2	V2	R3	C1	0.0	7.5	5.0	10.0	0.0
BL	D2	V2	R3	C2	10.0	0.0	0.0	0.0	2.5
BL	D2	V2	R3	C3	10.0	10.0	10.0	5.0	5.0
BL	D2	V2	R3	C4	10.0	10.0	0.0	5.0	0.0
BL	D2	V2	R3	C5	10.0	10.0	5.0	5.0	2.5
BL	D2	V2	R3	C6	5.0	0.0	10.0	0.0	0.0
LA	D2	V2	R3	C1	2.5	5.0	5.0	0.0	10.0
LA	D2	V2	R3	C2	7.5	0.0	0.0	7.5	0.0
LA	D2	V2	R3	C3	7.5	10.0	10.0	0.0	10.0
LA	D2	V2	R3	C4	10.0	10.0	0.0	0.0	0.0
LA	D2	V2	R3	C5	0.0	5.0	0.0	0.0	5.0
LA	D2	V2	R3	C6	2.5	0.0	0.0	5.0	0.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor
[b] D1=1 cm, D2 = 2 cm
[c] V1=187 L/ha, V2=748 L/ha

Table A.10: Point injection growth chamber study data(continued)

Application [a]	Depth [b]	Volume [c]	Rep.	Count	1 cm	2 cm	3 cm	4 cm	5 cm
CK	D2	V2	R4	C1	10.0	10.0	2.5	2.5	10.0
CK	D2	V2	R4	C2	10.0	0.0	5.0	0.0	0.0
CK	D2	V2	R4	C3	10.0	0.0	0.0	0.0	2.5
CK	D2	V2	R4	C4	10.0	0.0	2.5	5.0	0.0
CK	D2	V2	R4	C5	10.0	0.0	0.0	2.5	7.5
CK	D2	V2	R4	C6	10.0	10.0	7.5	0.0	0.0
BL	D2	V2	R4	C1	10.0	10.0	2.5	0.0	0.0
BL	D2	V2	R4	C2	10.0	10.0	5.0	0.0	0.0
BL	D2	V2	R4	C3	5.0	5.0	7.5	10.0	5.0
BL	D2	V2	R4	C4	10.0	10.0	2.5	0.0	0.0
BL	D2	V2	R4	C5	7.5	7.5	0.0	5.0	0.0
BL	D2	V2	R4	C6	10.0	5.0	5.0	0.0	0.0
LA	D2	V2	R4	C1	5.0	5.0	0.0	10.0	10.0
LA	D2	V2	R4	C2	10.0	10.0	5.0	0.0	0.0
LA	D2	V2	R4	C3	5.0	2.5	0.0	0.0	0.0
LA	D2	V2	R4	C4	7.5	5.0	2.5	0.0	0.0
LA	D2	V2	R4	C5	7.5	7.5	0.0	7.5	0.0
LA	D2	V2	R4	C6	10.0	0.0	0.0	0.0	0.0

[a] CK=Check, BL=Cyanazine, LA=Alachlor
[b] D1=1 cm, D2 = 2 cm
[c] V1=187 L/ha, V2=748 L/ha

APPENDIX B. EFFECTIVENESS STUDY DATA

Table B.1: Oat counts for the 1989 season using a point injector with a 5 cm point spacing

Herbicide	Application	Replication	Subrep.	Count 1	Count 2	Count 3
Atrazine	Injected	1	1	39	20	17
Atrazine	Injected	1	2	24	8	5
Atrazine	Injected	1	3	42	23	20
Atrazine	Injected	2	1	24	10	6
Atrazine	Injected	2	2	39	31	25
Atrazine	Injected	2	3	37	23	17
Atrazine	Injected	3	1	32	20	17
Atrazine	Injected	3	2	36	28	27
Atrazine	Injected	3	3	26	19	16
Atrazine	Injected	4	1	36	15	3
Atrazine	Injected	4	2	19	10	6
Atrazine	Injected	4	3	51	25	14
Atrazine	Sprayed	1	1	27	3	0
Atrazine	Sprayed	1	2	41	6	0
Atrazine	Sprayed	1	3	50	14	0
Atrazine	Sprayed	2	1	27	0	0
Atrazine	Sprayed	2	2	32	7	0
Atrazine	Sprayed	2	3	23	5	1
Atrazine	Sprayed	3	1	16	4	2
Atrazine	Sprayed	3	2	26	0	0
Atrazine	Sprayed	3	3	32	3	2
Atrazine	Sprayed	4	1	43	0	0
Atrazine	Sprayed	4	2	38	0	0
Atrazine	Sprayed	4	3	34	0	0
Propachlor	Injected	1	1	43	34	12
Propachlor	Injected	1	2	58	31	7
Propachlor	Injected	1	3	42	16	2
Propachlor	Injected	2	1	34	28	14
Propachlor	Injected	2	2	34	25	22
Propachlor	Injected	2	3	24	25	19
Propachlor	Injected	3	1	36	30	24
Propachlor	Injected	3	2	36	30	23
Propachlor	Injected	3	3	38	34	30
Propachlor	Injected	4	1	34	12	0

Table B.2: Oat counts for the 1989 season using a point injector with a 5 cm point spacing(continued)

Herbicide	Application	Replication	Subrep.	Count 1	Count 2	Count 3
Propachlor	Injected	4	2	34	18	15
Propachlor	Injected	4	3	41	30	27
Propachlor	Sprayed	1	1	31	31	
Propachlor	Sprayed	1	2	38	21	
Propachlor	Sprayed	1	3	47	40	
Propachlor	Sprayed	2	1	27	25	17
Propachlor	Sprayed	2	2	20	17	10
Propachlor	Sprayed	2	3	26	19	16
Propachlor	Sprayed	3	1	17	12	9
Propachlor	Sprayed	3	2	17	10	4
Propachlor	Sprayed	3	3	21	17	13
Propachlor	Sprayed	4	1	42	25	18
Propachlor	Sprayed	4	2	36	16	5
Propachlor	Sprayed	4	3	21	3	0
EPTC	Injected	1	1	34	29	17
EPTC	Injected	1	2	53	39	36
EPTC	Injected	1	3	44	36	28
EPTC	Injected	2	1	23	18	13
EPTC	Injected	2	2	38	28	21
EPTC	Injected	2	3	28	28	12
EPTC	Injected	3	1	33	27	17
EPTC	Injected	3	2	20	13	11
EPTC	Injected	3	3	40	34	25
EPTC	Injected	4	1	26	9	1
EPTC	Injected	4	2	24	1	0
EPTC	Injected	4	3	35	10	3
EPTC	Sprayed	1	1	9	1	0
EPTC	Sprayed	1	2	6	1	1
EPTC	Sprayed	1	3	2	2	1
EPTC	Sprayed	2	1	0	0	0
EPTC	Sprayed	2	2	0	0	0
EPTC	Sprayed	2	3	1	1	0
EPTC	Sprayed	3	1	1	0	0
EPTC	Sprayed	3	2	5	0	0

Table B.3: Oat counts for the 1989 season using a point injector with a 5 cm point spacing(continued)

Herbicide	Application	Replication	Subrep.	Count 1	Count 2	Count 3
EPTC	Sprayed	3	3	0	0	0
EPTC	Sprayed	4	1	0	0	
EPTC	Sprayed	4	2	0	0	
EPTC	Sprayed	4	3	0	0	
CHECK	None	1	1	28	28	22
CHECK	None	1	2	18	12	12
CHECK	None	1	3	56	35	39
CHECK	None	2	1	39	34	24
CHECK	None	2	2	29	23	18
CHECK	None	2	3	36	36	27
CHECK	None	3	1	39	27	11
CHECK	None	3	2	50	23	21
CHECK	None	3	3	43	29	26
CHECK	None	4	1	31	26	
CHECK	None	4	2	35	22	
CHECK	None	4	3	43	35	
Butylate	Injected	1	1	25	6	
Butylate	Injected	1	2	33	11	
Butylate	Injected	1	3	40	2	
Butylate	Injected	2	1	45	26	4
Butylate	Injected	2	2	30	21	10
Butylate	Injected	2	3	31	30	15
Butylate	Injected	3	1	22	17	15
Butylate	Injected	3	2	28	18	10
Butylate	Injected	3	3	29	37	26
Butylate	Injected	4	1	14	10	4
Butylate	Injected	4	2	13	7	4
Butylate	Injected	4	3	27	17	10
Butylate	Sprayed	1	1	6	0	0
Butylate	Sprayed	1	2	1	0	0
Butylate	Sprayed	1	3	0	0	0
Butylate	Sprayed	2	1	10	2	0
Butylate	Sprayed	2	2	0	0	0
Butylate	Sprayed	2	3	14	15	12
Butylate	Sprayed	3	1	4	1	0

Table B.4: Oat counts for the 1989 season using a point injector with a 5 cm point spacing(continued)

Herbicide	Application	Replication	Subrep.	Count 1	Count 2	Count 3
Butylate	Sprayed	3	2	0	0	0
Butylate	Sprayed	3	3	2	2	1
Butylate	Sprayed	4	1	0	0	0
Butylate	Sprayed	4	2	0	0	0
Butylate	Sprayed	4	3	7	0	0
Trifluralin	Injected	1	1	30	20	13
Trifluralin	Injected	1	2	38	21	19
Trifluralin	Injected	1	3	31	30	26
Trifluralin	Injected	2	1	32	23	
Trifluralin	Injected	2	2	34	25	24
Trifluralin	Injected	2	3	45	37	30
Trifluralin	Injected	3	1	39	35	
Trifluralin	Injected	3	2	27	15	
Trifluralin	Injected	3	3	31	24	
Trifluralin	Injected	4	1	36	9	5
Trifluralin	Injected	4	2	28	7	6
Trifluralin	Injected	4	3	38	23	16
Trifluralin	Sprayed	1	1	14	2	0
Trifluralin	Sprayed	1	2	15	2	0
Trifluralin	Sprayed	1	3	13	2	0
Trifluralin	Sprayed	2	1	32	3	
Trifluralin	Sprayed	2	2	20	2	
Trifluralin	Sprayed	2	3	6	2	
Trifluralin	Sprayed	3	1	16	0	1
Trifluralin	Sprayed	3	2	14	6	4
Trifluralin	Sprayed	3	3	10	3	2
Trifluralin	Sprayed	4	1	26	19	2
Trifluralin	Sprayed	4	2	15	7	3
Trifluralin	Sprayed	4	3	9	0	0

Table B.5: Average oat counts for the 1989 season using a point injector with a 2.5 cm point spacing

Herbicide	Application	Replication	Count 1	Count 2	Count 3
Atrazine	Band Injected	1	87.67	78.67	78.67
Atrazine	Band Injected	2	103.33	93.33	91.33
Atrazine	Band Injected	3	65.0	56.33	58.00
Atrazine	Band Injected	4	49.33	48.33	54.67
Atrazine	Sprayed/disked	1	154.30	128.33	90.33
Atrazine	Sprayed/disked	2	74.0	35.67	40.67
Atrazine	Sprayed/disked	3	60.33	35.67	40.00
EPTC	Band Injected	1	6.33	6.33	4.67
EPTC	Band Injected	2	41.00	31.00	31.33
EPTC	Band Injected	3	29.0	13.67	9.33
EPTC	Band Injected	4	18.33	15.67	18.33
EPTC	Sprayed/disked	1	2.0	1.33	0.00
EPTC	Sprayed/disked	2	0.33	0.00	0.00
EPTC	Sprayed/disked	3	0.67	0.00	0.00
EPTC	Sprayed/disked	4	2.00	1.67	1.00
Butylate	Band Injected	1	37.67	34.33	32.33
Butylate	Band Injected	2	61.00	62.67	60.33
Butylate	Band Injected	3	75.67	83.67	78.33
Butylate	Band Injected	4	45.67	43.00	41.33
Butylate	Sprayed/disked	1	4.33	3.25	5.33
Butylate	Sprayed/disked	2	25.33	22.33	21.67
Butylate	Sprayed/disked	3	17.00	18.00	27.00
Butylate	Sprayed/disked	4	4.33	4.67	7.00
Trifluralin	Band Injected	1	70.00	66.00	58.67
Trifluralin	Band Injected	2	99.67	102.33	90.33
Trifluralin	Band Injected	3	150.00	159.33	140.00
Trifluralin	Band Injected	4	69.00	72.33	77.00
Trifluralin	Sprayed/disked	1	49.33	40.00	38.67
Trifluralin	Sprayed/disked	2	27.67	27.33	23.33
Trifluralin	Sprayed/disked	3	17.67	15.67	12.33
Trifluralin	Sprayed/disked	4	20.00	16.67	15.67
Check	None	1	84.67	84.67	79.33
Check	None	2	64.00	66.67	69.33
Check	None	3	82.0	87.67	73.00
Check	None	4	31.33	32.22	40.33

Table B.6: Oat counts for the 1990 season using a point injector with a 2.5 cm point spacing

Herbicide	Application	Replication	Subrep.	Count 1	Count 2
Atrazine	Injected	1	1	13	35
Atrazine	Injected	1	2	21	59
Atrazine	Injected	1	3	7	34
Atrazine	Injected	2	1	17	39
Atrazine	Injected	2	2	24	46
Atrazine	Injected	2	3	13	29
Atrazine	Injected	3	1	20	34
Atrazine	Injected	3	2	36	63
Atrazine	Injected	3	3	23	47
Atrazine	Sprayed	1	1	25	31
Atrazine	Sprayed	1	2	36	60
Atrazine	Sprayed	1	3	27	45
Atrazine	Sprayed	2	1	20	40
Atrazine	Sprayed	2	2	59	78
Atrazine	Sprayed	2	3	39	45
Atrazine	Sprayed	3	1	23	27
Atrazine	Sprayed	3	2	40	50
Atrazine	Sprayed	3	3	22	33
EPTC	Injected	1	1	7	8
EPTC	Injected	1	2	7	8
EPTC	Injected	1	3	1	2
EPTC	Injected	2	1	7	16
EPTC	Injected	2	2	8	12
EPTC	Injected	2	3	2	4
EPTC	Injected	3	1	6	7
EPTC	Injected	3	2	4	6
EPTC	Injected	3	3	1	1
EPTC	Sprayed	1	1	3	8
EPTC	Sprayed	1	2	3	4
EPTC	Sprayed	1	3	1	2
EPTC	Sprayed	2	1	2	5
EPTC	Sprayed	2	2	5	8
EPTC	Sprayed	2	3	4	5
EPTC	Sprayed	3	1	4	7
EPTC	Sprayed	3	2	23	32
EPTC	Sprayed	3	3	2	3

Table B.7: Oat counts for the 1990 season using a point injector with a 2.5 cm point spacing(continued)

Herbicide	Application	Replication	Subrep.	Count 1	Count 2
Check	None	1	1	34	48
Check	None	1	2	46	86
Check	None	1	3	16	28
Check	None	2	1	41	50
Check	None	2	2	82	139
Check	None	2	3	37	56
Check	None	3	1	13	49
Check	None	3	2	63	128
Check	None	3	3	34	60
Alachlor	Injected	1	1	4	38
Alachlor	Injected	1	2	5	45
Alachlor	Injected	1	3	7	31
Alachlor	Injected	2	1	12	39
Alachlor	Injected	2	2	28	65
Alachlor	Injected	2	3	9	40
Alachlor	Injected	3	1	22	38
Alachlor	Injected	3	2	41	83
Alachlor	Injected	3	3	26	48
Alachlor	Sprayed	1	1	9	32
Alachlor	Sprayed	1	2	32	70
Alachlor	Sprayed	1	3	2	29
Alachlor	Sprayed	2	1	5	20
Alachlor	Sprayed	2	2	20	49
Alachlor	Sprayed	2	3	2	25
Alachlor	Sprayed	3	1	24	47
Alachlor	Sprayed	3	2	33	73
Alachlor	Sprayed	3	3	13	54
butylate	Injected	1	1	14	26
butylate	Injected	1	2	19	58
butylate	Injected	1	3	4	23
butylate	Injected	2	1	12	26
butylate	Injected	2	2	38	84
butylate	Injected	2	3	10	36
butylate	Injected	3	1	30	49
butylate	Injected	3	2	30	64

Table B.8: Oat counts for the 1990 season using a point injector with a 2.5 cm point spacing(continued)

Herbicide	Application	Replication	Subrep.	Count 1	Count 2
butylate	Injected	3	3	12	45
butylate	Sprayed	1	1	17	50
butylate	Sprayed	1	2	38	96
butylate	Sprayed	1	3	21	38
butylate	Sprayed	2	1	20	49
butylate	Sprayed	2	2	55	98
butylate	Sprayed	2	3	16	40
butylate	Sprayed	3	1	11	39
butylate	Sprayed	3	2	28	57
butylate	Sprayed	3	3	13	39
Trifluralin	Injected	1	1	12	29
Trifluralin	Injected	1	2	30	58
Trifluralin	Injected	1	3	14	29
Trifluralin	Injected	2	1	16	38
Trifluralin	Injected	2	2	38	75
Trifluralin	Injected	2	3	12	26
Trifluralin	Injected	3	1	21	41
Trifluralin	Injected	3	2	40	68
Trifluralin	Injected	3	3	20	37
Trifluralin	Sprayed	1	1	10	16
Trifluralin	Sprayed	1	2	22	39
Trifluralin	Sprayed	1	3	6	13
Trifluralin	Sprayed	2	1	5	14
Trifluralin	Sprayed	2	2	19	25
Trifluralin	Sprayed	2	3	9	23
Trifluralin	Sprayed	3	1	10	23
Trifluralin	Sprayed	3	2	41	52
Trifluralin	Sprayed	3	3	7	15

Table B.9: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied

Plot	Application	Count 1	Count 2
1	Band Sprayed	1	1
1	Band Sprayed	1	0
1	Band Sprayed	1	0
1	Band Sprayed	1	0
1	Band Sprayed	1	0
1	Band Sprayed	2	0
1	Band Sprayed	2	0
1	Band Sprayed	2	0
1	Band Sprayed	2	1
1	Band Sprayed	2	0
1	Band Sprayed	3	0
1	Band Sprayed	3	0
1	Band Sprayed	3	0
1	Band Sprayed	3	0
1	Band Sprayed	3	0
1	Band Sprayed	4	1
1	Band Sprayed	4	0
1	Band Sprayed	4	1
1	Band Sprayed	4	1
1	Band Sprayed	4	0
1	Band Sprayed	5	1
1	Band Sprayed	5	0
1	Band Sprayed	5	6
1	Band Sprayed	5	0
1	Band Sprayed	5	0
1	Band Sprayed	6	0
1	Band Sprayed	6	0
1	Band Sprayed	6	0
1	Band Sprayed	6	1
1	Band Sprayed	6	0
2	Band Sprayed	1	1
2	Band Sprayed	1	0
2	Band Sprayed	1	0
2	Band Sprayed	1	0
2	Band Sprayed	1	0

Table B.10: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
2	Band Sprayed	2	1
2	Band Sprayed	2	0
2	Band Sprayed	2	2
2	Band Sprayed	2	0
2	Band Sprayed	2	1
2	Band Sprayed	3	0
2	Band Sprayed	3	1
2	Band Sprayed	3	1
2	Band Sprayed	3	0
2	Band Sprayed	3	0
2	Band Sprayed	4	2
2	Band Sprayed	4	0
2	Band Sprayed	4	3
2	Band Sprayed	4	0
2	Band Sprayed	4	2
2	Band Sprayed	5	0
2	Band Sprayed	5	0
2	Band Sprayed	5	1
2	Band Sprayed	5	0
2	Band Sprayed	5	0
2	Band Sprayed	6	0
2	Band Sprayed	6	0
2	Band Sprayed	6	0
2	Band Sprayed	6	1
2	Band Sprayed	6	0
3	Band Sprayed	1	0
3	Band Sprayed	1	0
3	Band Sprayed	1	2
3	Band Sprayed	1	0
3	Band Sprayed	1	0
3	Band Sprayed	2	0
3	Band Sprayed	2	0
3	Band Sprayed	2	2
3	Band Sprayed	2	0
3	Band Sprayed	2	0

Table B.11: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
3	Band Sprayed	3	0
3	Band Sprayed	3	0
3	Band Sprayed	3	1
3	Band Sprayed	3	1
3	Band Sprayed	3	0
3	Band Sprayed	4	0
3	Band Sprayed	4	0
3	Band Sprayed	4	0
3	Band Sprayed	4	0
3	Band Sprayed	4	0
3	Band Sprayed	5	0
3	Band Sprayed	5	0
3	Band Sprayed	5	0
3	Band Sprayed	5	0
3	Band Sprayed	5	0
3	Band Sprayed	6	0
3	Band Sprayed	6	0
3	Band Sprayed	6	0
3	Band Sprayed	6	0
3	Band Sprayed	6	0
4	Band Sprayed	1	0
4	Band Sprayed	1	0
4	Band Sprayed	1	0
4	Band Sprayed	1	0
4	Band Sprayed	1	0
4	Band Sprayed	2	0
4	Band Sprayed	2	0
4	Band Sprayed	2	0
4	Band Sprayed	2	0
4	Band Sprayed	2	1
4	Band Sprayed	3	1
4	Band Sprayed	3	2
4	Band Sprayed	3	2
4	Band Sprayed	3	0
4	Band Sprayed	3	1

Table B.12: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
4	Band Sprayed	4	0
4	Band Sprayed	4	0
4	Band Sprayed	4	0
4	Band Sprayed	4	0
4	Band Sprayed	4	0
4	Band Sprayed	5	0
4	Band Sprayed	5	0
4	Band Sprayed	5	0
4	Band Sprayed	5	0
4	Band Sprayed	5	0
4	Band Sprayed	6	0
4	Band Sprayed	6	0
4	Band Sprayed	6	0
4	Band Sprayed	6	0
4	Band Sprayed	6	0
5	Band Sprayed	1	0
5	Band Sprayed	1	0
5	Band Sprayed	1	1
5	Band Sprayed	1	0
5	Band Sprayed	1	0
5	Band Sprayed	2	1
5	Band Sprayed	2	1
5	Band Sprayed	2	1
5	Band Sprayed	2	1
5	Band Sprayed	2	1
5	Band Sprayed	3	1
5	Band Sprayed	3	6
5	Band Sprayed	3	1
5	Band Sprayed	3	2
5	Band Sprayed	3	0
5	Band Sprayed	4	1
5	Band Sprayed	4	1
5	Band Sprayed	4	0
5	Band Sprayed	4	0
5	Band Sprayed	4	0

Table B.13: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
5	Band Sprayed	5	0
5	Band Sprayed	5	0
5	Band Sprayed	5	0
5	Band Sprayed	5	0
5	Band Sprayed	5	0
5	Band Sprayed	6	0
5	Band Sprayed	6	0
5	Band Sprayed	6	0
5	Band Sprayed	6	0
5	Band Sprayed	6	0
6	Band Sprayed	1	0
6	Band Sprayed	1	4
6	Band Sprayed	1	0
6	Band Sprayed	1	0
6	Band Sprayed	1	4
6	Band Sprayed	2	1
6	Band Sprayed	2	1
6	Band Sprayed	2	2
6	Band Sprayed	2	0
6	Band Sprayed	2	0
6	Band Sprayed	3	2
6	Band Sprayed	3	0
6	Band Sprayed	3	1
6	Band Sprayed	3	0
6	Band Sprayed	3	0
6	Band Sprayed	4	2
6	Band Sprayed	4	0
6	Band Sprayed	4	0
6	Band Sprayed	4	0
6	Band Sprayed	4	0
6	Band Sprayed	5	1
6	Band Sprayed	5	0
6	Band Sprayed	5	0
6	Band Sprayed	5	0
6	Band Sprayed	5	0

Table B.14: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
6	Band Sprayed	6	0
6	Band Sprayed	6	0
6	Band Sprayed	6	0
6	Band Sprayed	6	0
6	Band Sprayed	6	0
7	Band Sprayed	1	0
7	Band Sprayed	1	0
7	Band Sprayed	1	2
7	Band Sprayed	1	0
7	Band Sprayed	1	0
7	Band Sprayed	2	2
7	Band Sprayed	2	0
7	Band Sprayed	2	1
7	Band Sprayed	2	0
7	Band Sprayed	2	0
7	Band Sprayed	3	1
7	Band Sprayed	3	0
7	Band Sprayed	3	5
7	Band Sprayed	3	1
7	Band Sprayed	3	2
7	Band Sprayed	4	0
7	Band Sprayed	4	0
7	Band Sprayed	4	0
7	Band Sprayed	4	0
7	Band Sprayed	4	0
7	Band Sprayed	5	0
7	Band Sprayed	5	1
7	Band Sprayed	5	0
7	Band Sprayed	5	0
7	Band Sprayed	5	0
7	Band Sprayed	6	0
7	Band Sprayed	6	0
7	Band Sprayed	6	1
7	Band Sprayed	6	1
7	Band Sprayed	6	0

Table B.15: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
8	Band Sprayed	1	0
8	Band Sprayed	1	0
8	Band Sprayed	1	7
8	Band Sprayed	1	0
8	Band Sprayed	1	0
8	Band Sprayed	2	2
8	Band Sprayed	2	1
8	Band Sprayed	2	3
8	Band Sprayed	2	1
8	Band Sprayed	2	0
8	Band Sprayed	3	1
8	Band Sprayed	3	0
8	Band Sprayed	3	2
8	Band Sprayed	3	3
8	Band Sprayed	3	13
8	Band Sprayed	4	1
8	Band Sprayed	4	1
8	Band Sprayed	4	0
8	Band Sprayed	4	0
8	Band Sprayed	4	0
8	Band Sprayed	5	0
8	Band Sprayed	5	0
8	Band Sprayed	5	1
8	Band Sprayed	5	0
8	Band Sprayed	5	1
8	Band Sprayed	6	0
8	Band Sprayed	6	0
8	Band Sprayed	6	0
8	Band Sprayed	6	0
8	Band Sprayed	6	0
1	Band Injected	1	0
1	Band Injected	1	0
1	Check	1	1
1	Band Injected	1	0
1	Band Injected	1	0

Table B.16: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
1	Band Injected	2	0
1	Band Injected	2	0
1	Check	2	4
1	Band Injected	2	0
1	Band Injected	2	0
1	Band Injected	3	0
1	Band Injected	3	1
1	Check	3	3
1	Band Injected	3	0
1	Band Injected	3	0
1	Band Injected	4	0
1	Band Injected	4	5
1	Check	4	13
1	Band Injected	4	0
1	Band Injected	4	2
1	Band Injected	5	0
1	Band Injected	5	0
1	Check	5	3
1	Band Injected	5	0
1	Band Injected	5	0
1	Band Injected	6	0
1	Band Injected	6	0
1	Check	6	2
1	Band Injected	6	0
1	Band Injected	6	0
2	Band Injected	1	0
2	Band Injected	1	0
2	Check	1	2
2	Band Injected	1	0
2	Band Injected	1	0
2	Band Injected	2	0
2	Band Injected	2	0
2	Check	2	2
2	Band Injected	2	0
2	Band Injected	2	0

Table B.17: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
2	Band Injected	3	0
2	Band Injected	3	0
2	Check	3	32
2	Band Injected	3	0
2	Band Injected	3	0
2	Band Injected	4	1
2	Band Injected	4	1
2	Check	4	14
2	Band Injected	4	0
2	Band Injected	4	0
2	Band Injected	5	0
2	Band Injected	5	0
2	Check	5	11
2	Band Injected	5	0
2	Band Injected	5	0
2	Band Injected	6	0
2	Band Injected	6	0
2	Check	6	7
2	Band Injected	6	0
2	Band Injected	6	0
3	Band Injected	1	0
3	Band Injected	1	0
3	Check	1	2
3	Band Injected	1	0
3	Band Injected	1	0
3	Band Injected	2	0
3	Band Injected	2	0
3	Check	2	4
3	Band Injected	2	0
3	Band Injected	2	0
3	Band Injected	3	0
3	Band Injected	3	1
3	Check	3	2
3	Band Injected	3	0
3	Band Injected	3	0

Table B.18: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
3	Band Injected	4	0
3	Band Injected	4	0
3	Check	4	0
3	Band Injected	4	0
3	Band Injected	4	0
3	Band Injected	5	1
3	Band Injected	5	0
3	Check	5	5
3	Band Injected	5	0
3	Band Injected	5	0
3	Band Injected	6	0
3	Band Injected	6	0
3	Check	6	1
3	Band Injected	6	0
3	Band Injected	6	0
4	Band Injected	1	0
4	Band Injected	1	0
4	Check	1	3
4	Band Injected	1	0
4	Band Injected	1	0
4	Band Injected	2	0
4	Band Injected	2	0
4	Check	2	0
4	Band Injected	2	0
4	Band Injected	2	0
4	Band Injected	3	3
4	Band Injected	3	0
4	Check	3	14
4	Band Injected	3	0
4	Band Injected	3	0
4	Band Injected	4	0
4	Band Injected	4	0
4	Check	4	5
4	Band Injected	4	0
4	Band Injected	4	0

Table B.19: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
4	Band Injected	5	0
4	Band Injected	5	0
4	Check	5	5
4	Band Injected	5	0
4	Band Injected	5	0
4	Band Injected	6	0
4	Band Injected	6	0
4	Check	6	2
4	Band Injected	6	0
4	Band Injected	6	0
5	Band Injected	1	0
5	Band Injected	1	0
5	Check	1	5
5	Band Injected	1	0
5	Band Injected	1	0
5	Band Injected	2	0
5	Band Injected	2	0
5	Check	2	3
5	Band Injected	2	1
5	Band Injected	2	0
5	Band Injected	3	0
5	Band Injected	3	1
5	Check	3	14
5	Band Injected	3	1
5	Band Injected	3	0
5	Band Injected	4	1
5	Band Injected	4	3
5	Check	4	10
5	Band Injected	4	0
5	Band Injected	4	0
5	Band Injected	5	0
5	Band Injected	5	0
5	Check	5	11
5	Band Injected	5	0
5	Band Injected	5	0

Table B.20: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
5	Band Injected	6	0
5	Band Injected	6	0
5	Check	6	1
5	Band Injected	6	0
5	Band Injected	6	0
6	Band Injected	1	0
6	Band Injected	1	0
6	Check	1	8
6	Band Injected	1	0
6	Band Injected	1	0
6	Band Injected	2	0
6	Band Injected	2	1
6	Check	2	5
6	Band Injected	2	0
6	Band Injected	2	0
6	Band Injected	3	0
6	Band Injected	3	0
6	Check	3	49
6	Band Injected	3	1
6	Band Injected	3	0
6	Band Injected	4	0
6	Band Injected	4	0
6	Check	4	9
6	Band Injected	4	0
6	Band Injected	4	0
6	Band Injected	5	0
6	Band Injected	5	0
6	Check	5	7
6	Band Injected	5	0
6	Band Injected	5	0
6	Band Injected	6	0
6	Band Injected	6	0
6	Check	6	9
6	Band Injected	6	0
6	Band Injected	6	0

Table B.21: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
7	Band Injected	1	2
7	Band Injected	1	0
7	Check	1	56
7	Band Injected	1	0
7	Band Injected	1	0
7	Band Injected	2	0
7	Band Injected	2	1
7	Check	2	10
7	Band Injected	2	0
7	Band Injected	2	0
7	Band Injected	3	1
7	Band Injected	3	0
7	Check	3	22
7	Band Injected	3	1
7	Band Injected	3	0
7	Band Injected	4	0
7	Band Injected	4	0
7	Check	4	3
7	Band Injected	4	0
7	Band Injected	4	0
7	Band Injected	5	1
7	Band Injected	5	0
7	Check	5	8
7	Band Injected	5	0
7	Band Injected	5	0
7	Band Injected	6	0
7	Band Injected	6	0
7	Check	6	3
7	Band Injected	6	0
7	Band Injected	6	0
8	Band Injected	1	0
8	Band Injected	1	0
8	Check	1	9
8	Band Injected	1	1
8	Band Injected	1	0

Table B.22: Weed counts for the 1991 season using a point injector with a 5 cm point spacing attached to a planter, atrazine and alachlor applied(continued)

Plot	Application	Count 1	Count 2
8	Band Injected	2	0
8	Band Injected	2	0
8	Check	2	15
8	Band Injected	2	0
8	Band Injected	2	0
8	Band Injected	3	6
8	Band Injected	3	4
8	Check	3	0
8	Band Injected	3	0
8	Band Injected	3	0
8	Band Injected	4	0
8	Band Injected	4	1
8	Check	4	8
8	Band Injected	4	0
8	Band Injected	4	0
8	Band Injected	5	0
8	Band Injected	5	0
8	Check	5	14
8	Band Injected	5	0
8	Band Injected	5	0
8	Band Injected	6	0
8	Band Injected	6	0
8	Check	6	1
8	Band Injected	6	0
8	Band Injected	6	0

APPENDIX C. DATA FOR PERSISTENCE STUDY

Table C.1: Concentration of soil samples taken from the bare surface plots in the persistence study over a 21 day period

Day	Application	Replication	Propachlor Concentration (kg/ha)	Atrazine Concentration (kg/ha)	Alachlor Concentration (kg/ha)
0	Sprayed	1	0.823	0.874	0.959
0	Sprayed	2	1.923	1.136	1.117
0	Sprayed	3	1.303	1.923	1.550
0	Injected	1	0.109	0.276	0.280
0	Injected	2	0.036	0.210	0.029
0	Injected	3	0.026	0.435	0.024
1	Sprayed	1	0.998	1.052	1.150
1	Sprayed	2	1.001	1.209	1.134
1	Sprayed	3	1.084	1.582	1.258
1	Injected	1	0.061	0.199	0.200
1	Injected	2	0.039	0.179	0.050
1	Injected	3	0.044	0.365	0.061
2	Sprayed	1	0.918	1.115	1.116
2	Sprayed	2	0.932	1.284	1.118
2	Sprayed	3	1.473	2.166	1.707
2	Injected	1	0.205	0.431	0.425
2	Injected	2	0.031	0.245	0.035
2	Injected	3	0.035	0.354	0.052
3	Sprayed	1	1.272	1.555	1.595
3	Sprayed	2	0.822	1.346	1.111
3	Sprayed	3	1.043	0.767	1.373
3	Injected	1	0.103	0.271	0.334
3	Injected	2	0.025	0.248	0.065
3	Injected	3	0.026	0.312	0.033

Table C.1 (Continued)

4	Sprayed	1	0.759	0.932	0.944
4	Sprayed	2	0.566	0.845	0.714
4	Sprayed	3	0.736	1.267	0.993
4	Injected	1	0.098	0.267	0.263
4	Injected	2	0.025	0.166	0.050
4	Injected	3	0.014	0.170	0.022
6	Sprayed	1	0.672	1.198	1.086
6	Sprayed	2	0.621	1.229	0.909
6	Sprayed	3	0.600	1.376	0.948
6	Injected	1	0.061	0.296	0.277
6	Injected	2	0.021	0.249	0.071
6	Injected	3	0.018	0.227	0.053
8	Sprayed	1	0.569	1.147	0.951
8	Sprayed	2	0.493	1.231	0.843
8	Sprayed	3	0.490	1.320	0.848
8	Injected	1	0.093	0.217	0.208
8	Injected	2	0.069	0.202	0.059
8	Injected	3	0.065	0.168	0.038
10	Sprayed	1	0.077	0.156	0.104
10	Sprayed	2	0.171	0.784	0.376
10	Sprayed	3	0.110	0.578	0.255
10	Injected	1	0.051	0.080	0.063
10	Injected	2	0.050	0.078	0.033
10	Injected	3	.	.	.

Table C.1 (Continued)

12	Sprayed	1	0.145	0.916	0.623
12	Sprayed	2	0.189	1.177	0.647
12	Sprayed	3	0.237	1.763	0.959
12	Injected	1	0.043	0.170	0.144
12	Injected	2	0.040	0.211	0.061
12	Injected	3	0.039	0.205	0.043
15	Sprayed	1	0.050	0.881	0.350
15	Sprayed	2	0.050	0.847	0.184
15	Sprayed	3	0.039	0.658	0.105
15	Injected	1	0.045	0.150	0.134
15	Injected	2	0.041	0.119	0.034
15	Injected	3	0.034	0.089	0.000
18	Sprayed	1	0.063	0.981	0.27
18	Sprayed	2	0.068	0.917	0.21
18	Sprayed	3	0.065	0.663	0.12
18	Injected	1	0.064	0.125	0.14
18	Injected	2	0.064	0.137	0.01
18	Injected	3	0.046	0.117	0.01
21	Sprayed	1	0.072	0.951	0.32
21	Sprayed	2	0.074	1.244	0.28
21	Sprayed	3	0.059	0.673	0.12
21	Injected	1	.	.	.
21	Injected	2	0.057	0.193	0.04
21	Injected	3	0.050	0.112	0.01

Table C.2: Concentration of soil samples taken from the residue surface plots in the persistence study over a 21 day period

Day	Application	Replication	Propachlor Concentration (kg/ha)	Atrazine Concentration (kg/ha)	Alachlor Concentration (kg/ha)
0	Sprayed	1	0.274	0.671	0.706
0	Sprayed	2	0.328	0.769	0.575
0	Sprayed	3	0.274	1.093	.
0	Injected	1	0.021	0.114	0.064
0	Injected	2	0.018	0.156	.
0	Injected	3	0.034	0.431	.
1	Sprayed	1	0.240	0.525	0.672
1	Sprayed	2	0.392	0.800	0.588
1	Sprayed	3	0.236	0.719	0.264
1	Injected	1	0.016	0.085	0.092
1	Injected	2	0.017	0.195	.
1	Injected	3	0.099	0.416	0.097
2	Sprayed	1	0.201	0.619	0.632
2	Sprayed	2	0.281	0.759	0.456
2	Sprayed	3	0.096	0.544	0.000
2	Injected	1	0.027	0.101	0.079
2	Injected	2	0.036	0.218	0.059
2	Injected	3	0.033	0.330	.
3	Sprayed	1	0.309	0.988	0.882
3	Sprayed	2	0.308	0.991	0.563
3	Sprayed	3	0.137	0.852	0.125
3	Injected	1	0.013	0.088	.
3	Injected	2	0.019	0.229	.
3	Injected	3	0.034	0.496	0.000

Table C.2 (Continued)

4	Sprayed	1	0.107	0.607	0.430
4	Sprayed	2	0.153	0.681	0.300
4	Sprayed	3	.	0.323	0.000
4	Injected	1	.	0.041	.
4	Injected	2	.	0.127	.
4	Injected	3	.	0.196	.
6	Sprayed	1	0.049	0.460	0.141
6	Sprayed	2	0.000	0.015	0.000
6	Sprayed	3	0.000	0.168	0.048
6	Injected	1	.	.	.
6	Injected	2	.	.	.
6	Injected	3	.	.	.
8	Sprayed	1	0.156	0.996	0.501
8	Sprayed	2	0.112	0.914	0.307
8	Sprayed	3	0.085	0.607	0.188
8	Injected	1	0.070	0.085	0.044
8	Injected	2	0.074	0.188	0.068
8	Injected	3	0.068	0.201	0.046
10	Sprayed	1	0.048	0.345	0.099
10	Sprayed	2	0.090	1.162	0.343
10	Sprayed	3	0.061	0.459	0.118
10	Injected	1	0.065	0.090	0.040
10	Injected	2	.	0.062	0.023
10	Injected	3	.	0.052	0.018

Table C.2 (Continued)

12	Sprayed	1	0.052	1.021	0.382
12	Sprayed	2	0.063	1.287	0.368
12	Sprayed	3	0.046	0.783	0.186
12	Injected	1	0.037	0.096	0.035
12	Injected	2	0.038	0.220	0.059
12	Injected	3	0.041	0.229	0.051
15	Sprayed	1	0.050	0.881	0.350
15	Sprayed	2	0.050	0.847	0.184
15	Sprayed	3	0.039	0.658	0.105
15	Injected	1	0.043	0.097	0.032
15	Injected	2	0.034	0.146	0.036
15	Injected	3	0.039	0.271	0.053
18	Sprayed	1	0.063	0.981	0.277
18	Sprayed	2	0.068	0.917	0.211
18	Sprayed	3	0.065	0.663	0.126
18	Injected	1	0.060	0.131	0.029
18	Injected	2	.	0.108	0.022
18	Injected	3	.	0.212	.
21	Sprayed	1	0.072	0.951	0.322
21	Sprayed	2	0.084	1.244	0.275
21	Sprayed	3	0.059	0.673	0.125
21	Injected	1	0.061	0.137	0.024
21	Injected	2	0.060	0.204	0.058
21	Injected	3	0.054	0.175	0.027

Table C.3: Concentration of residue samples taken from the residue surface plots in the persistence study over a 21 day period

Day	Application	Replication	Propachlor Concentration (kg/ha)	Atrazine Concentration (kg/ha)	Alachlor Concentration (kg/ha)
0	Sprayed	1	0.647	0.997	0.539
0	Sprayed	2	0.739	1.142	0.644
0	Sprayed	3	.	.	0.141
0	Injected	1	0.013	0.003	0.007
0	Injected	2	0.018	0.017	0.010
0	Injected	3	0.015	0.009	0.007
1	Sprayed	1	0.390	0.716	0.362
1	Sprayed	2	0.600	0.978	0.545
1	Sprayed	3	0.449	0.863	0.405
1	Injected	1	0.013	0.004	0.004
1	Injected	2	0.011	0.001	0.003
1	Injected	3	0.015	0.009	0.006
2	Sprayed	1	0.066	0.682	0.293
2	Sprayed	2	0.012	0.016	0.007
2	Sprayed	3	0.037	0.612	0.149
2	Injected	1	0.012	0.018	0.009
2	Injected	2	0.016	0.015	0.014
2	Injected	3	0.011	0.007	0.003
3	Sprayed	1	0.046	0.458	0.162
3	Sprayed	2	0.105	0.844	0.289
3	Sprayed	3	0.065	0.460	0.139
3	Injected	1	0.012	0.003	0.003
3	Injected	2	0.014	0.012	0.008
3	Injected	3	0.017	0.046	0.022

Table C.3 (Continued)

4	Sprayed	1	0.083	0.722	0.213
4	Sprayed	2	0.090	0.634	0.239
4	Sprayed	3	0.030	0.458	0.124
4	Injected	1	0.012	0.005	.
4	Injected	2	0.014	0.024	0.015
4	Injected	3	0.014	0.026	0.016
6	Sprayed	1	0.031	0.591	0.160
6	Sprayed	2	0.032	0.581	0.155
6	Sprayed	3	0.025	0.443	0.133
6	Injected	1	0.012	0.005	0.007
6	Injected	2	.	0.008	0.007
6	Injected	3	0.013	0.065	0.026
8	Sprayed	1	0.021	0.477	0.137
8	Sprayed	2	0.027	0.576	0.167
8	Sprayed	3	0.014	0.258	0.064
8	Injected	1	0.011	0.003	0.025
8	Injected	2	0.000	0.007	0.004
8	Injected	3	0.000	0.008	0.000
10	Sprayed	1	0.012	0.152	0.037
10	Sprayed	2	0.011	0.051	0.015
10	Sprayed	3	0.000	0.091	0.031
10	Injected	1	0.000	0.002	0.000
10	Injected	2	0.000	0.002	0.000
10	Injected	3	0.000	0.010	0.000

Table C.3 (Continued)

12	Sprayed	1	0.021	0.194	0.041
12	Sprayed	2	0.022	0.101	0.024
12	Sprayed	3	0.000	0.056	0.017
12	Injected	1	0.021	0.003	0.000
12	Injected	2	0.000	0.006	0.000
12	Injected	3	0.000	0.006	0.000
15	Sprayed	1	0.021	0.134	0.039
15	Sprayed	2	0.020	0.130	0.025
15	Sprayed	3	0.000	0.050	0.014
15	Injected	1	0.020	0.002	0.007
15	Injected	2	0.000	0.010	0.000
15	Injected	3	0.021	0.006	0.000
18	Sprayed	1	0.022	0.123	0.025
18	Sprayed	2	0.023	0.168	0.066
18	Sprayed	3	0.021	0.090	0.023
18	Injected	1	0.021	0.007	0.007
18	Injected	2	0.000	0.005	0.000
18	Injected	3	0.000	0.003	.
21	Sprayed	1	0.022	0.105	0.025
21	Sprayed	2	0.022	0.092	0.029
21	Sprayed	3	0.000	0.074	0.023
21	Injected	1	0.000	0.003	0.000
21	Injected	2	0.000	0.009	0.000
21	Injected	3	0.000	0.007	0.000

APPENDIX D. RUNOFF AND LEACHING DATA

Table D.1: No tillage/band sprayed/replication 1 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

NO TILLAGE BAND SPRAY 1

Area = 0.001394 ha Slope = 1.8 % Residue Cover = 54.5 %
Alachlor applied = 1.977 kg/ha
Atrazine applied = 1.495 kg/ha
Propachlor applied = 1.707 kg/ha
Runoff started 12.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	1.4	42.02	4405.0
2	1.3	48.08	1425.0
3	4.8	112.05	1526.0
4	5.0	123.61	1258.0
5	10.0	146.29	1068.0
6	20.0	212.84	922.0
7	30.0	198.95	789.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	20.5	66.1	1.5	3799.0	4528.0	1323.0
2	34.6	87.1	1.9	5369.0	38087.0	3391.0
3	153.8	292.4	1.0	27503.0	71646.0	6470.0
4	167.5	260.2	50.5	22516.0	73171.0	664.0
5	155.9	216.0	46.2	14224.0	28335.0	0.0
6	109.5	126.7	23.4	5932.0	15287.0	0.0
7	35.3	50.1	1.3	2666.0	8724.0	0.0

Table D.1 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	13.38	0.025	11.00
2	14.65	0.026	3.75
3	19.50	0.234	35.71
4	24.50	0.266	33.48
5	34.50	0.629	67.27
6	54.50	1.832	168.98
7	84.50	2.569	202.75

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0510	0.1643	0.0038	0.0418	0.0498	0.0146
2	0.1419	0.3931	0.0087	0.0619	0.1925	0.0273
3	3.7366	7.2277	0.0330	1.0439	2.7506	0.2583
4	8.1901	14.1463	1.3747	1.7976	5.2001	0.2805
5	18.0034	27.7408	4.2828	2.7545	7.1061	0.2805
6	38.0626	50.9453	8.5676	3.7569	9.6894	0.2805
7	47.1307	63.8153	8.8913	4.2974	11.4582	0.2805
Flow weighted concentrations, ppb	84.449	114.345	15.931	8218.0	21911.6	536.4

Flow weighted erosion = 936.111 ppm

Total alachlor losses = 51.42810 g/ha
Total atrazine losses = 75.27348 g/ha
Total propachlor losses = 9.17175 g/ha

Percent of alachlor applied lost = 2.601 %
Percent of atrazine applied lost = 5.035 %
Percent of propachlor applied lost = 0.537 %

Table D.2: No tillage/band sprayed/replication 2 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

NO TILLAGE BAND SPRAY 2

Area = 0.001394 ha Slope = 1.0 % Residue Cover = 61.6 %
Alachlor applied = 2.765 kg/ha
Atrazine applied = 4.541 kg/ha
Propachlor applied = 2.314 kg/ha
Runoff started 10.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	2.5	23.28	2077.0
2	1.7	34.89	1572.0
3	4.8	91.59	1362.0
4	5.0	115.03	1775.0
5	10.0	127.50	1775.0
6	20.0	127.50	1286.0
7	30.0	129.46	699.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	57.6	150.4	0.9	71.0	0.0	0.0
2	116.2	228.2	10.4	6231.0	2382.4	1526.0
3	153.8	292.4	1.1	5305.0	4764.6	3052.0
4	57.6	257.0	1.1	5867.3	7167.7	2507.0
5	119.5	342.9	15.5	6429.7	9571.3	1063.0
6	42.6	178.2	1.2	23408.0	11975.0	3991.5
7	55.2	89.6	5.1	23557.0	40104.0	6920.0

Table D.2 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	12.50	0.025	5.20
2	14.20	0.026	4.01
3	19.00	0.189	25.78
4	24.00	0.247	43.95
5	34.00	0.548	97.44
6	54.00	1.097	141.19
7	84.00	1.672	116.89

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.1441	0.3764	0.0023	0.0004	0.0000	0.0000
2	0.4405	0.9585	0.0289	0.0254	0.0096	0.0061
3	3.3490	6.4885	0.0490	0.1621	0.1324	0.0848
4	4.7735	12.8439	0.0757	0.4200	0.4475	0.1950
5	11.3247	31.6429	0.9238	1.0465	1.3801	0.2986
6	15.9979	51.1911	1.0521	4.3515	3.0708	0.8621
7	25.2259	66.1649	1.9014	7.1050	7.7584	1.6710
Flow weighted concentrations, ppb	66.316	173.940	4.999	16353.3	17857.2	3846.0

Flow weighted erosion = 1140.870 ppm

Total alachlor losses = 32.33091 g/ha
Total atrazine losses = 73.92335 g/ha
Total propachlor losses = 3.57237 g/ha

Percent of alachlor applied lost = 1.169 %
Percent of atrazine applied lost = 1.628 %
Percent of propachlor applied lost = 0.154 %

Table D.3: No tillage/band sprayed/replication 3 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

NO TILLAGE BAND SPRAY 3

Area = 0.001394 ha Slope = 1.4 % Residue Cover = 71.2 %
Alachlor applied = 2.322 kg/ha
Atrazine applied = 2.291 kg/ha
Propachlor applied = 1.986 kg/ha
Runoff started 8.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	3.4	17.25	4513.0
2	0.4	14.41	3540.0
3	5.2	121.15	2498.0
4	4.8	143.25	1899.0
5	10.0	155.82	1472.0
6	20.0	158.50	1370.0
7	30.0	164.15	986.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	260.8	1138.9	15.0	0.0	0.0	0.0
2	293.4	985.0	51.6	0.0	0.0	985.0
3	316.8	869.7	84.1	2176.0	8037.0	502.0
4	244.8	669.2	50.5	4314.0	16074.0	1496.0
5	192.8	335.8	32.1	17769.0	24111.0	7465.0
6	105.0	167.6	11.6	12645.0	15244.0	6841.0
7	74.1	70.6	14.0	8001.0	8414.0	16593.0

Table D.3 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	11.40	0.025	11.40
2	11.81	0.003	0.90
3	17.01	0.271	67.76
4	21.81	0.296	56.22
5	31.81	0.670	98.75
6	51.81	1.364	186.98
7	81.81	2.119	209.06

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.6559	2.8642	0.0376	0.0000	0.0000	0.0000
2	0.7303	3.1140	0.0507	0.0000	0.0000	0.0009
3	9.3055	26.6546	2.3266	0.1474	0.5446	0.0349
4	16.5421	46.4366	3.8207	0.3900	1.4482	0.1190
5	29.4635	68.9411	5.9740	2.1447	3.8293	0.8562
6	43.7811	91.7988	7.5585	4.5092	6.6797	2.1354
7	59.4836	106.7681	10.5295	6.1818	8.4387	5.6042
Flow weighted concentrations, ppb	125.312	224.924	22.182	9795.8	13372.1	8880.6

Flow weighted erosion = 1327.677 ppm

Total alachlor losses = 65.66543 g/ha
Total atrazine losses = 115.20677 g/ha
Total propachlor losses = 16.13370 g/ha

Percent of alachlor applied lost = 2.828 %
Percent of atrazine applied lost = 5.029 %
Percent of propachlor applied lost = 0.812 %

Table D.4: No tillage/band injection/replication 1 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

NO TILLAGE BAND INJ 1

Area = 0.001394 ha Slope = 1.7 % Residue Cover = 62.1 %
Alachlor applied = 2.296 kg/ha
Atrazine applied = 2.203 kg/ha
Propachlor applied = 1.879 kg/ha
Runoff started 11.50 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	1.7	33.97	3167.0
2	1.3	44.24	3451.0
3	6.0	76.59	1385.0
4	5.0	87.07	1196.0
5	10.0	119.04	1245.0
6	20.0	118.28	726.0
7	30.0	152.56	739.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	191.4	579.0	27.2	2623.0	0.0	935.0
2	218.5	601.3	32.4	1004.0	0.0	614.0
3	301.7	707.5	59.7	11629.0	0.0	489.8
4	495.0	833.6	267.5	13081.0	0.0	8803.0
5	402.5	698.6	201.5	1143.0	0.0	4465.0
6	327.0	585.3	136.1	6362.0	0.0	0.0
7	169.5	263.6	60.5	6362.0	0.0	0.0

Table D.4 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	13.17	0.024	7.74
2	14.47	0.025	8.55
3	20.50	0.199	27.54
4	25.50	0.187	22.42
5	35.50	0.512	63.81
6	55.50	1.018	73.94
7	85.50	1.970	145.62

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.4662	1.4105	0.0664	0.0203	0.0000	0.0072
2	1.0056	2.8950	0.1464	0.0289	0.0000	0.0125
3	6.9991	16.9510	1.3332	0.3491	0.0000	0.0260
4	16.2705	32.5649	6.3430	0.6424	0.0000	0.2233
5	36.8832	68.3424	16.6622	0.7153	0.0000	0.5082
6	70.1791	127.9380	30.5192	1.1857	0.0000	0.5082
7	103.5700	179.8741	42.4336	2.1122	0.0000	0.5082
Flow weighted concentrations, ppb	263.181	457.078	107.828	6041.5	0.0	1453.7

Flow weighted erosion = 887.621 ppm

Total alachlor losses = 105.68217 g/ha
Total atrazine losses = 179.87413 g/ha
Total propachlor losses = 42.94178 g/ha

Percent of alachlor applied lost = 4.603 %
Percent of atrazine applied lost = 8.165 %
Percent of propachlor applied lost = 2.285 %

Table D.5: No tillage/band injection/replication 2 runoff data

RAINFALL SIMULATION STUDY   AMES, IA., AUGUST, 1990

NO TILLAGE BAND INJ   2

Area = 0.001394 ha Slope = 1.7 % Residue Cover = 64.6 %
Alachlor applied = 1.054 kg/ha
Atrazine applied = 1.010 kg/ha
Propachlor applied = 0.856 kg/ha
Runoff started 11.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	1.3	41.24	3089.0
2	1.3	46.36	1965.0
3	4.9	115.32	1497.0
4	5.0	120.99	1079.0
5	10.0	141.59	1155.0
6	20.0	164.55	1231.0
7	30.0	175.85	1211.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	60.6	438.3	2.0	8996.0	3461.0	1399.0
2	70.6	442.0	1.0	12861.0	4456.0	2809.0
3	45.9	329.1	1.0	18808.0	14827.0	4393.0
4	38.4	276.1	1.0	20895.0	38799.0	6950.0
5	54.8	201.5	0.9	6314.0	580.0	3672.0
6	38.5	93.4	1.4	5751.0	717.0	1135.0
7	22.1	45.2	2.0	1083.0	1391.0	0.0

Table D.5 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	12.33	0.024	7.29
2	13.60	0.025	4.98
3	18.50	0.243	36.42
4	23.50	0.260	28.10
5	33.50	0.609	70.41
6	53.50	1.416	174.43
7	83.50	2.270	275.06

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.1427	1.0324	0.0048	0.0656	0.0252	0.0102
2	0.3214	2.1511	0.0075	0.1297	0.0474	0.0242
3	1.4370	10.1506	0.0328	0.8147	0.5875	0.1842
4	2.4365	17.3379	0.0583	1.4019	1.6779	0.3795
5	5.7748	29.6111	0.1143	1.8465	1.7187	0.6381
6	11.2258	42.8321	0.3182	2.8496	1.8438	0.8360
7	16.2416	53.0885	0.7653	3.1475	2.2264	0.8360
Flow weighted concentrations, ppb	33.510	109.532	1.579	5274.9	3731.1	1401.1

Flow weighted erosion = 1229.602 ppm

Total alachlor losses = 19.38914 g/ha
Total atrazine losses = 55.31489 g/ha
Total propachlor losses = 1.60135 g/ha

Percent of alachlor applied lost = 1.840 %
Percent of atrazine applied lost = 5.477 %
Percent of propachlor applied lost = 0.187 %

Table D.6: No tillage/band injection/replication 3 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

NO TILLAGE BAND INJ 3
Area = 0.001394 ha Slope = 1.3 % Residue Cover = 73.2 %
Alachlor applied = 1.685 kg/ha
Atrazine applied = 1.323 kg/ha
Propachlor applied = 1.309 kg/ha
Runoff started 11.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	2.3	27.14	1649.0
2	1.6	37.84	2343.0
3	6.2	102.34	1398.0
4	5.0	119.44	2070.0
5	10.0	124.65	1307.0
6	20.0	126.43	1265.0
7	30.0	129.09	1072.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	29.4	116.0	2.6	10120.0	3807.0	4598.0
2	22.3	86.5	1.9	4440.0	3467.7	2401.0
3	24.9	80.7	1.6	3280.0	3128.2	2078.9
4	29.0	68.2	2.4	2950.0	4058.3	1754.9
5	30.5	63.8	3.3	7244.0	7241.0	3057.0
6	29.1	41.8	4.6	12354.0	27668.0	4040.0
7	18.7	22.6	3.2	21226.0	51635.0	5023.0

Table D.6 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	13.25	0.026	4.34
2	14.85	0.026	6.11
3	21.00	0.271	37.88
4	26.00	0.257	53.22
5	36.00	0.536	70.14
6	56.00	1.088	137.72
7	86.00	1.666	178.75

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0772	0.3046	0.0068	0.0439	0.0165	0.0199
2	0.1352	0.5296	0.0117	0.0710	0.0377	0.0346
3	0.8093	2.7139	0.0542	0.1953	0.1562	0.1134
4	1.5538	4.4646	0.1166	0.3523	0.3722	0.2068
5	3.1892	7.8830	0.2925	0.8604	0.8801	0.4212
6	6.3547	12.4300	0.7896	2.5618	4.6905	0.9776
7	9.4708	16.2043	1.3179	6.3558	13.9200	1.8754
Flow weighted concentrations, ppb	24.472	41.871	3.405	13019.9	28515.3	3841.8

Flow weighted erosion = 1259.786 ppm

Total alachlor losses = 15.82663 g/ha
Total atrazine losses = 30.12430 g/ha
Total propachlor losses = 3.19328 g/ha

Percent of alachlor applied lost = 0.939 %
Percent of atrazine applied lost = 2.277 %
Percent of propachlor applied lost = 0.244 %

Table D.7: Ridge tillage/band sprayed/replication 1 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

RIDGE TILL BAND SPRAY 1

Area = 0.001394 ha Slope = 2.0 % Residue Cover = 44.9 %
Alachlor applied = 1.538 kg/ha
Atrazine applied = 1.683 kg/ha
Propachlor applied = 1.756 kg/ha
Runoff started 7.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	2.5	23.17	5254.0
2	2.3	25.84	3284.0
3	4.2	112.92	2093.0
4	5.0	123.98	1368.0
5	10.0	132.70	1217.0
6	20.0	136.18	1150.0
7	30.0	143.39	1079.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	179.1	649.6	1.2	3175.0	3399.0	0.0
2	151.6	355.9	1.1	8489.0	7992.0	2456.0
3	124.2	317.1	1.7	1186.0	5858.0	4721.5
4	113.8	248.3	17.0	2097.0	3724.0	6987.0
5	82.9	172.0	17.7	3468.0	1590.0	8094.0
6	72.5	136.1	18.4	1631.0	1924.0	6437.0
7	34.4	53.0	9.6	2276.0	2258.0	6672.0

Table D.7 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	9.50	0.025	13.10
2	11.83	0.026	8.51
3	16.00	0.202	42.43
4	21.00	0.267	36.51
5	31.00	0.571	69.53
6	51.00	1.172	134.85
7	81.00	1.851	199.84

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.4445	1.6124	0.0031	0.0416	0.0445	0.0000
2	0.8364	2.5323	0.0060	0.1139	0.1126	0.0209
3	3.3502	8.9499	0.0402	0.1642	0.3611	0.2213
4	6.3847	15.5708	0.4940	0.2408	0.4971	0.4764
5	11.1175	25.3892	1.5045	0.4819	0.6077	1.0392
6	19.6132	41.3364	3.6607	0.7018	0.8671	1.9072
7	25.9803	51.1389	5.4375	1.1567	1.3184	3.2406
Flow weighted concentrations, ppb	63.161	124.324	13.219	2291.4	2611.7	6419.6

Flow weighted erosion = 1225.691 ppm

Total alachlor losses = 27.13703 g/ha
Total atrazine losses = 52.45731 g/ha
Total propachlor losses = 8.67811 g/ha

Percent of alachlor applied lost = 1.764 %
Percent of atrazine applied lost = 3.117 %
Percent of propachlor applied lost = 0.494 %

Table D.8: Ridge tillage/band sprayed/replication 2 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

RIDGE TILL BAND SPRAY 2

Area = 0.001394 ha Slope = 1.3 % Residue Cover = 51.0 %
Alachlor applied = 2.726 kg/ha
Atrazine applied = 2.714 kg/ha
Propachlor applied = 3.335 kg/ha
Runoff started 11.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	6.0	9.66	3731.0
2	4.4	13.17	2467.0
3	5.6	37.38	2538.0
4	5.0	62.26	1790.0
5	10.0	108.60	2003.0
6	20.0	105.11	1666.0
7	30.0	119.82	1318.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	100.2	174.8	28.4	0.0	0.0	0.0
2	90.2	167.9	33.5	1540.0	1924.0	2211.0
3	90.3	219.4	28.9	1104.0	1957.7	4072.0
4	87.2	179.9	21.6	1109.0	1990.0	4270.0
5	80.8	112.3	31.1	763.0	2023.0	2440.0
6	63.1	120.6	8.1	617.0	2053.0	5675.1
7	42.6	63.6	10.3	1375.0	2083.0	6190.0

Table D.8 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	17.00	0.025	9.31
2	21.36	0.025	6.10
3	27.00	0.091	23.04
4	32.00	0.134	23.99
5	42.00	0.467	93.66
6	62.00	0.904	150.79
7	92.00	1.546	203.98

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.2492	0.4349	0.0706	0.0000	0.0000	0.0000
2	0.4718	0.8490	0.1532	0.0094	0.0117	0.0135
3	1.2897	2.8360	0.4153	0.0348	0.0568	0.1073
4	2.4569	5.2446	0.7044	0.0614	0.1046	0.2097
5	6.2290	10.4892	2.1587	0.1329	0.2940	0.4383
6	11.9332	21.3914	2.8873	0.2259	0.6036	1.2940
7	18.5205	31.2275	4.4800	0.5064	1.0285	2.5567
Flow weighted concentrations, ppb	58.038	97.857	14.039	991.3	2013.3	5004.5

Flow weighted erosion = 1598.341 ppm

Total alachlor losses = 19.02691 g/ha
Total atrazine losses = 32.25597 g/ha
Total propachlor losses = 7.03665 g/ha

Percent of alachlor applied lost = 0.698 %
Percent of atrazine applied lost = 1.189 %
Percent of propachlor applied lost = 0.211 %

Table D.9: Ridge tillage/band sprayed/replication 3 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

RIDGE TILL BAND SPRAY 3

Area = 0.001394 ha Slope = 1.4 % Residue Cover = 28.3 %
Alachlor applied = 2.273 kg/ha
Atrazine applied = 2.204 kg/ha
Propachlor applied = 2.849 kg/ha
Runoff started 14.50 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	1.8	32.20	4613.0
2	2.2	26.64	3947.0
3	4.6	131.68	2951.0
4	5.0	151.23	1884.0
5	10.0	163.72	2031.0
6	20.0	155.88	1698.0
7	30.0	159.09	1758.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	32.4	175.3	1.5	2798.0	2005.0	0.0
2	20.0	122.3	2.0	1833.0	1993.0	2059.0
3	49.9	135.3	6.3	3613.0	1981.0	2853.0
4	79.8	148.3	10.5	1240.0	478.0	5086.0
5	83.1	145.0	13.3	1153.0	563.0	4666.0
6	26.4	84.7	1.9	3458.0	214.0	6095.0
7	28.3	38.3	2.7	819.0	89.0	14396.0

Table D.9 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	16.25	0.024	11.19
2	18.43	0.025	9.87
3	23.00	0.258	76.46
4	28.00	0.325	61.34
5	38.00	0.704	143.17
6	58.00	1.341	227.92
7	88.00	2.052	361.25

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0783	0.4235	0.0037	0.0313	0.0224	0.0000
2	0.1281	0.7282	0.0088	0.0494	0.0421	0.0203
3	1.4178	4.2249	0.1711	0.3257	0.1936	0.2385
4	4.0120	9.0467	0.5135	0.4017	0.2229	0.5504
5	9.8604	19.2487	1.4460	0.5668	0.3035	1.2184
6	13.3996	30.6063	1.7020	1.3549	0.3523	2.6076
7	19.2073	38.4702	2.2561	1.6508	0.3844	7.8082
Flow weighted concentrations, ppb	40.614	81.346	4.771	1852.3	431.4	8761.5

Flow weighted erosion = 1880.908 ppm

Total alachlor losses = 20.85807 g/ha
Total atrazine losses = 38.85466 g/ha
Total propachlor losses = 10.06427 g/ha

Percent of alachlor applied lost = 0.918 %
Percent of atrazine applied lost = 1.763 %
Percent of propachlor applied lost = 0.353 %

Table D.10: Ridge tillage/band injection/replication 1 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

RIDGE TILL BAND INJ 1

Area = 0.001394 ha Slope = 2.7 % Residue Cover = 49.0 %
Alachlor applied = 1.460 kg/ha
Atrazine applied = 1.446 kg/ha
Propachlor applied = 1.050 kg/ha
Runoff started 5.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	1.4	42.12	4278.0
2	0.9	66.11	3017.0
3	6.7	143.01	2348.0
4	5.0	159.83	2020.0
5	10.0	173.68	1682.0
6	20.0	180.77	1439.0
7	30.0	184.54	1319.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	32.1	314.7	0.0	1882.0	3669.0	0.0
2	47.6	344.6	1.3	2128.0	1213.0	2239.0
3	24.5	394.3	0.9	5193.0	2577.0	3606.5
4	45.1	306.4	1.1	7297.0	3941.0	4974.0
5	53.8	258.4	1.6	4790.0	2085.0	5542.0
6	25.6	183.5	1.1	7053.0	1669.0	7316.0
7	23.4	115.1	0.9	5490.0	1254.0	7576.0

Table D.10 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	6.42	0.026	11.02
2	7.32	0.026	7.73
3	14.00	0.411	96.58
4	19.00	0.344	69.50
5	29.00	0.747	125.78
6	49.00	1.555	224.00
7	79.00	2.382	314.40

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0823	0.8073	0.0000	0.0207	0.0404	0.0000
2	0.2040	1.6877	0.0033	0.0372	0.0498	0.0173
3	1.2098	17.8730	0.0407	0.5387	0.2987	0.3656
4	2.7591	28.3981	0.0798	1.0459	0.5726	0.7113
5	6.7772	47.6954	0.1986	1.6483	0.8348	1.4084
6	10.7581	76.2324	0.3743	3.2282	1.2087	3.0471
7	16.3309	103.6461	0.6006	4.9542	1.6029	5.4290
Flow weighted concentrations, ppb	29.754	188.835	1.094	5835.4	1888.0	6394.6

Flow weighted erosion = 1544.419 ppm

Total alachlor losses = 21.28514 g/ha
Total atrazine losses = 105.24907 g/ha
Total propachlor losses = 6.02958 g/ha

Percent of alachlor applied lost = 1.458 %
Percent of atrazine applied lost = 7.279 %
Percent of propachlor applied lost = 0.574 %

Table D.11: Ridge tillage/band injection/replication 2 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

RIDGE TILL BAND INJ 2

Area = 0.001394 ha Slope = 0.6 % Residue Cover = 35.4 %
Alachlor applied = 0.622 kg/ha
Atrazine applied = 0.730 kg/ha
Propachlor applied = 0.425 kg/ha
Runoff started 19.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	3.4	18.07	2548.0
2	2.1	29.03	2900.0
3	5.5	105.98	2422.0
4	5.0	136.66	1860.0
5	10.0	169.53	1868.0
6	20.0	197.95	1670.0
7	30.0	200.42	1596.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	112.4	205.4	0.0	1990.0	3375.0	0.0
2	83.0	195.2	1.0	2631.0	4517.0	0.0
3	98.5	171.6	1.7	2104.0	3673.0	0.0
4	68.3	123.2	1.1	2084.0	3264.0	0.0
5	31.3	91.3	1.1	2720.0	991.0	0.0
6	36.8	57.9	1.1	937.0	866.0	0.0
7	13.9	31.2	0.0	2278.0	1539.0	0.0

Table D.11 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	22.42	0.027	6.78
2	24.50	0.026	7.54
3	30.00	0.250	60.78
4	35.00	0.294	54.72
5	45.00	0.729	136.35
6	65.00	1.702	284.66
7	95.00	2.586	413.16

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.2984	0.5453	0.0000	0.0135	0.0229	0.0000
2	0.5137	1.0515	0.0027	0.0333	0.0569	0.0000
3	2.9808	5.3495	0.0450	0.1612	0.2802	0.0000
4	4.9873	8.9689	0.0776	0.2753	0.4588	0.0000
5	7.2687	15.6271	0.1571	0.6461	0.5939	0.0000
6	13.5337	25.4861	0.3409	0.9128	0.8404	0.0000
7	17.1279	33.5614	0.3409	1.8540	1.4763	0.0000
Flow weighted concentrations, ppb	30.510	59.784	0.607	1923.3	1531.4	0.0

Flow weighted erosion = 1714.239 ppm

Total alachlor losses = 18.98195 g/ha
Total atrazine losses = 35.03768 g/ha
Total propachlor losses = 0.34092 g/ha

Percent of alachlor applied lost = 3.052 %
Percent of atrazine applied lost = 4.800 %
Percent of propachlor applied lost = 0.080 %

Table D.12: Ridge tillage/band injection/replication 3 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

RIDGE TILL BAND INJ 3

Area = 0.001394 ha Slope = 0.8 % Residue Cover = 28.3 %
Alachlor applied = 0.656 kg/ha
Atrazine applied = 0.770 kg/ha
Propachlor applied = 0.771 kg/ha
Runoff started 16.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	0.5	115.78	2445.0
2	0.6	95.99	2552.0
3	5.8	153.79	3628.0
4	5.0	187.37	2745.0
5	10.0	194.56	1439.0
6	20.0	181.61	1776.0
7	30.0	196.00	2151.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	30.9	70.4	1.2	998.0	2685.0	0.0
2	25.7	63.6	1.0	1000.0	1454.0	0.0
3	18.1	78.8	1.0	1794.0	2910.0	0.0
4	22.0	84.4	1.7	1508.0	2300.0	0.0
5	32.4	59.5	2.4	2086.0	1690.0	0.0
6	21.0	31.9	1.8	2772.0	961.0	0.0
7	9.6	21.2	1.1	1208.0	921.0	0.0

Table D.12 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	16.53	0.026	6.46
2	17.16	0.026	6.64
3	22.99	0.385	140.05
4	27.99	0.402	110.72
5	37.99	0.837	120.54
6	57.99	1.562	277.74
7	87.99	2.527	544.56

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0815	0.1855	0.0032	0.0064	0.0173	0.0000
2	0.1482	0.3507	0.0059	0.0131	0.0270	0.0000
3	0.8447	3.3813	0.0432	0.2643	0.4346	0.0000
4	1.7301	6.7775	0.1117	0.4313	0.6892	0.0000
5	4.4415	11.7534	0.3142	0.6828	0.8929	0.0000
6	7.7212	16.7370	0.5922	1.4527	1.1598	0.0000
7	10.1474	22.0923	0.8778	2.1105	1.6614	0.0000
Flow weighted concentrations, ppb	17.600	38.318	1.522	1748.9	1376.8	0.0

Flow weighted erosion = 2088.625 ppm

Total alachlor losses = 12.25788 g/ha
Total atrazine losses = 23.75371 g/ha
Total propachlor losses = 0.87776 g/ha

Percent of alachlor applied lost = 1.869 %
Percent of atrazine applied lost = 3.085 %
Percent of propachlor applied lost = 0.114 %

Table D.13: Conventional tillage/band sprayed/replication 1 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

CONV TILL BAND SPRAY 1

Area = 0.001394 ha Slope = 2.4 % Residue Cover = 9.1 %
Alachlor applied = 3.246 kg/ha
Atrazine applied = 3.308 kg/ha
Propachlor applied = 4.181 kg/ha
Runoff started 9.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	4.8	12.32	4247.0
2	1.7	36.88	3495.0
3	5.5	69.17	4076.0
4	5.0	76.96	1947.0
5	10.0	93.78	2019.0
6	20.0	124.06	2180.0
7	30.0	152.99	2862.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	237.2	457.3	83.8	4243.0	1283.0	344.0
2	292.8	569.5	26.1	6232.0	1186.0	3974.0
3	185.4	368.1	17.0	3023.0	1089.0	2313.0
4	148.7	271.9	20.8	7427.0	1835.0	4579.0
5	61.3	117.7	8.4	11797.0	1683.0	3235.0
6	16.7	79.4	5.2	4381.0	1531.0	2478.0
7	22.8	30.5	2.0	916.0	559.0	0.0

Table D.13 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	13.83	0.026	10.88
2	15.50	0.026	9.27
3	21.00	0.163	66.76
4	26.00	0.165	32.26
5	36.00	0.403	81.52
6	56.00	1.066	232.89
7	86.00	1.971	565.56

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.6054	1.1670	0.2139	0.0462	0.0140	0.0037
2	1.3795	2.6725	0.2831	0.1039	0.0250	0.0406
3	4.4052	8.6803	0.5597	0.3058	0.0977	0.1950
4	6.8651	13.1786	0.9034	0.5453	0.1568	0.3427
5	9.3363	17.9227	1.2421	1.5070	0.2941	0.6064
6	11.1173	26.3869	1.7966	2.5273	0.6506	1.1835
7	15.6119	32.3975	2.1889	3.0454	0.9667	1.1835
Flow weighted concentrations, ppb	40.853	84.778	5.728	3048.0	967.6	1184.5

Flow weighted erosion = 2607.722 ppm

Total alachlor losses = 18.65723 g/ha
Total atrazine losses = 33.36421 g/ha
Total propachlor losses = 3.37243 g/ha

Percent of alachlor applied lost = 0.575 %
Percent of atrazine applied lost = 1.009 %
Percent of propachlor applied lost = 0.081 %

Table D.14: Conventional tillage/band sprayed/replication 2 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

CONV TILL BAND SPRAY 2

Area = 0.001394 ha Slope = 2.4 % Residue Cover = 15.6 %
Alachlor applied = 2.776 kg/ha
Atrazine applied = 2.823 kg/ha
Propachlor applied = 3.395 kg/ha
Runoff started 52.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	3.5	17.69	3803.0
2	1.1	54.10	2726.0
3	5.3	87.22	2650.0
4	5.0	121.73	2627.0
5	10.0	149.47	2309.0
6	20.0	208.01	2052.0
7	30.0	229.38	2176.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	36.2	81.6	0.5	1088.0	1469.0	0.0
2	28.5	84.8	0.5	1194.0	1362.0	0.0
3	15.5	90.0	0.4	1500.0	1569.0	0.0
4	71.2	173.4	4.1	1464.0	1774.0	0.0
5	62.6	113.2	4.9	1618.0	1979.0	0.0
6	47.8	98.4	5.6	1771.0	3453.0	2047.0
7	38.9	77.1	7.3	1091.0	2383.0	510.0

Table D.14 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	55.50	0.027	10.14
2	56.65	0.027	7.30
3	62.00	0.200	53.24
4	67.00	0.261	68.84
5	77.00	0.642	148.59
6	97.00	1.788	367.55
7	127.00	2.958	644.71

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0962	0.2168	0.0014	0.0110	0.0149	0.0000
2	0.1723	0.4435	0.0027	0.0197	0.0248	0.0000
3	0.4831	2.2472	0.0116	0.0996	0.1084	0.0000
4	2.3448	6.7816	0.1188	0.2004	0.2305	0.0000
5	6.3659	14.0517	0.4310	0.4408	0.5246	0.0000
6	14.9139	31.6539	1.4360	1.0918	1.7937	0.7524
7	26.4192	54.4515	3.5803	1.7951	3.3301	1.0812
Flow weighted concentrations, ppb	44.752	92.235	6.065	1380.5	2560.8	831.4

Flow weighted erosion = 2197.859 ppm

Total alachlor losses = 28.21437 g/ha
Total atrazine losses = 57.78155 g/ha
Total propachlor losses = 4.66145 g/ha

Percent of alachlor applied lost = 1.016 %
Percent of atrazine applied lost = 2.047 %
Percent of propachlor applied lost = 0.137 %

Table D.15: Conventional tillage/band sprayed/replication 3 runoff data

RAINFALL SIMULATION STUDY   AMES, IA., AUGUST, 1990

CONV TILL BAND SPRAY 3

Area = 0.001394 ha Slope = 0.8 % Residue Cover = 15.6 %
Alachlor applied = 4.872 kg/ha
Atrazine applied = 5.211 kg/ha
Propachlor applied = 6.045 kg/ha
Runoff started 30.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	8.3	7.30	2783.0
2	5.1	11.39	2194.0
3	4.6	31.49	2739.0
4	5.0	47.98	3536.0
5	10.0	65.63	3132.0
6	20.0	93.38	3024.0
7	30.0	110.68	2719.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	403.6	769.2	4.2	6432.0	0.0	0.0
2	299.4	529.8	90.9	6005.0	0.0	0.0
3	202.3	344.8	4.1	5157.0	1971.0	0.0
4	191.0	315.0	6.3	2775.0	3706.0	879.0
5	179.2	285.1	8.6	3069.0	839.0	727.0
6	43.8	91.9	4.9	159.0	898.0	575.0
7	34.2	56.5	0.9	716.0	1950.0	0.0

Table D.15 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	38.25	0.026	7.22
2	43.36	0.025	5.50
3	48.00	0.063	17.23
4	53.00	0.103	36.52
5	63.00	0.282	88.50
6	83.00	0.802	243.16
7	113.00	1.426	388.71

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	1.0441	1.9899	0.0108	0.0464	0.0000	0.0000
2	1.7930	3.3151	0.2383	0.0794	0.0000	0.0000
3	3.0628	5.4793	0.2638	0.1683	0.0340	0.0000
4	5.0295	8.7224	0.3291	0.2696	0.1693	0.0321
5	10.0795	16.7562	0.5717	0.5413	0.2436	0.0964
6	13.5924	24.1252	0.9639	0.5799	0.4619	0.2363
7	18.4705	32.1883	1.0994	0.8582	1.2199	0.2363
Flow weighted concentrations, ppb	67.737	118.044	4.032	1090.7	1550.4	300.3

Flow weighted erosion = 2877.274 ppm

Total alachlor losses = 19.32874 g/ha
Total atrazine losses = 33.40825 g/ha
Total propachlor losses = 1.33567 g/ha

Percent of alachlor applied lost = 0.397 %
Percent of atrazine applied lost = 0.641 %
Percent of propachlor applied lost = 0.022 %

Table D.16: Conventional tillage/band injection/replication 1 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

CONV TILL BAND INJ 1

Area = 0.001394 ha Slope = 2.7 % Residue Cover = 11.6 %
Alachlor applied = 1.054 kg/ha
Atrazine applied = 0.874 kg/ha
Propachlor applied = 0.754 kg/ha
Runoff started 20.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	4.3	13.86	1837.0
2	2.8	21.91	1902.0
3	5.0	57.47	2372.0
4	5.0	72.31	2685.0
5	10.0	94.87	3300.0
6	20.0	127.02	2656.0
7	30.0	148.65	3105.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	10.6	19.0	0.9	1762.0	1138.0	2360.0
2	12.0	19.7	1.4	1823.0	1378.0	0.0
3	13.4	20.4	1.9	758.0	371.0	0.0
4	7.5	13.6	1.3	820.0	432.0	0.0
5	6.7	9.5	0.8	735.0	264.0	0.0
6	3.2	4.0	0.8	759.0	162.0	0.0
7	2.9	2.7	0.8	0.0	106.0	0.0

Table D.16 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	24.25	0.025	4.66
2	27.00	0.026	4.93
3	32.00	0.123	29.35
4	37.00	0.155	41.80
5	47.00	0.407	134.79
6	67.00	1.091	290.51
7	97.00	1.915	596.17

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0268	0.0480	0.0023	0.0082	0.0053	0.0110
2	0.0579	0.0989	0.0059	0.0172	0.0121	0.0110
3	0.2234	0.3503	0.0296	0.0394	0.0230	0.0110
4	0.3399	0.5608	0.0492	0.0737	0.0410	0.0110
5	0.6128	0.9489	0.0802	0.1728	0.0766	0.0110
6	0.9620	1.3811	0.1631	0.3933	0.1237	0.0110
7	1.5173	1.8886	0.3163	0.3933	0.1869	0.0110
Flow weighted concentrations, ppb	4.053	5.045	0.845	356.8	169.6	10.0

Flow weighted erosion = 2935.604 ppm

Total alachlor losses = 1.91062 g/ha
Total atrazine losses = 2.07545 g/ha
Total propachlor losses = 0.32730 g/ha

Percent of alachlor applied lost = 0.181 %
Percent of atrazine applied lost = 0.237 %
Percent of propachlor applied lost = 0.043 %

Table D.17: Conventional tillage/band injection/replication 2 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

CONV TILL BAND INJ 2

Area = 0.001394 ha Slope = 1.4 % Residue Cover = 11.6 %
Alachlor applied = 0.792 kg/ha
Atrazine applied = 0.759 kg/ha
Propachlor applied = 0.540 kg/ha
Runoff started 39.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	4.9	12.73	6902.0
2	1.2	54.09	4453.0
3	4.9	71.78	2799.0
4	5.0	90.64	2276.0
5	10.0	107.55	2304.0
6	20.0	134.50	1781.0
7	30.0	153.97	2174.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	3.3	59.9	0.0	1435.0	3074.0	0.0
2	26.7	53.1	4.9	635.0	1618.0	0.0
3	22.3	35.7	1.8	486.0	1405.5	1394.0
4	21.6	34.6	1.2	1631.0	1193.0	2127.0
5	21.5	27.7	7.4	4698.0	635.0	1423.0
6	10.5	15.5	1.4	1614.0	665.0	2554.0
7	7.1	9.7	2.6	0.0	15.0	0.0

Table D.17 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	43.92	0.027	18.61
2	45.09	0.027	12.13
3	50.01	0.152	42.56
4	55.01	0.195	44.41
5	65.01	0.462	106.69
6	85.01	1.157	206.27
7	115.01	1.985	432.36

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.0088	0.1604	0.0000	0.0267	0.0572	0.0000
2	0.0813	0.3044	0.0133	0.0344	0.0768	0.0000
3	0.4196	0.8462	0.0408	0.0551	0.1367	0.0593
4	0.8403	1.5203	0.0647	0.1275	0.1896	0.1538
5	1.8340	2.8001	0.4090	0.6288	0.2574	0.3056
6	3.0485	4.5975	0.5687	0.9617	0.3946	0.8324
7	4.4580	6.5293	1.0868	0.9617	0.4010	0.8324
Flow weighted concentrations, ppb	11.132	16.305	2.714	1114.3	464.7	964.5

Flow weighted erosion = 2150.506 ppm

Total alachlor losses = 5.41971 g/ha
Total atrazine losses = 6.93030 g/ha
Total propachlor losses = 1.91926 g/ha

Percent of alachlor applied lost = 0.684 %
Percent of atrazine applied lost = 0.913 %
Percent of propachlor applied lost = 0.355 %

Table D.18: Conventional tillage/band injection/replication 3 runoff data

RAINFALL SIMULATION STUDY AMES, IA., AUGUST, 1990

CONV TILL BAND INJ 3

Area = 0.001394 ha Slope = 1.7 % Residue Cover = 9.1 %
Alachlor applied = 3.441 kg/ha
Atrazine applied = 4.924 kg/ha
Propachlor applied = 3.030 kg/ha
Runoff started 34.00 minutes after rainfall began

Sample Number	Interval Length (min)	Flowrate (cm/s)	Sediment Conc. (ppm)
1	4.0	14.05	5300.0
2	3.5	16.71	2762.0
3	5.5	33.22	4838.0
4	5.0	45.98	5121.0
5	10.0	75.77	4071.0
6	20.0	117.06	4225.0
7	30.0	141.96	2886.0

Sample	Concentration (ppb in water)			Concentration (ppb in sediment)		
Number	Alachlor	Atrazine	Propachlor	Alachlor	Atrazine	Propachlor
1	83.5	378.2	4.9	4398.0	6231.0	1613.0
2	29.2	241.1	4.7	4237.0	4180.0	2273.0
3	27.5	180.1	4.6	2279.0	2362.0	1189.0
4	20.0	108.7	0.8	1788.5	1983.0	0.0
5	1.0	70.3	0.8	1298.0	2326.0	0.0
6	0.5	48.5	0.8	1111.0	2649.0	0.0
7	4.4	32.4	0.9	1577.0	1734.0	0.0

Table D.18 (Continued)

Sample Number	Time after Rainfall Began (min)	Runoff (cm)	Erosion (kg/ha)
1	38.00	0.024	12.82
2	41.50	0.025	6.95
3	47.00	0.078	38.06
4	52.00	0.099	50.69
5	62.00	0.325	132.81
6	82.00	1.004	425.88
7	112.00	1.829	529.19

	Accumulated Losses in water			Accumulated Losses in sediment		
Sample Number	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)	Alachlor (g/ha)	Atrazine (g/ha)	Propachlor (g/ha)
1	0.2011	0.9107	0.0119	0.0564	0.0799	0.0207
2	0.2744	1.5163	0.0238	0.0859	0.1090	0.0365
3	0.4898	2.9264	0.0594	0.1726	0.1989	0.0817
4	0.6868	3.9969	0.0672	0.2633	0.2994	0.0817
5	0.7193	6.2817	0.0929	0.4356	0.6083	0.0817
6	0.7696	11.1480	0.1752	0.9088	1.7365	0.0817
7	1.5744	17.0726	0.3307	1.7433	2.6541	0.0817
Flow weighted concentrations, ppb	4.652	50.445	0.977	1457.1	2218.4	68.3

Flow weighted erosion = 3522.576 ppm

Total alachlor losses = 3.31771 g/ha
Total atrazine losses = 19.72669 g/ha
Total propachlor losses = 0.41244 g/ha

Percent of alachlor applied lost = 0.096 %
Percent of atrazine applied lost = 0.401 %
Percent of propachlor applied lost = 0.014 %

Table D.19: Leaching concentrations for chisel plow tillage/band-injected plots

Plot No.	Replication and position	Propachlor (ppb)	Atrazine (ppb)	Alachlor (ppb)	Weight (g)	Time after Rainfall begin (minutes)
1	2A	2.899	3.916	7.989	1346	107
2	1A	1.810	3.951	2.851	3508	49
2	1B	.000	3.026	3.951	3506	
2	1C	1.453	9.106	5.549	3601	
2	2A	72.849	219.800	120.174	3503	41
2	2B	7.811	173.71	83.311	3459	
2	2C	14.507	121.25	61.044	3544	
2	3A	16.032	82.927	55.503	3526	53
2	3B	12.566	55.753	38.980	3386	
2	3C	4.276	43.010	28.548	3511	

Table D.20: Leaching concentrations for chisel plow tillage/band-sprayed plots

Plot No.	Replication and position	Propachlor (ppb)	Atrazine (ppb)	Alachlor (ppb)	Weight (g)	Time after Rainfall begin (minutes)
1	1A	4.691	23.044	9.679	378	97
1	2A	13.250	38.545	22.385	1176	79
2	1A	.000	54.103	13.642	3712	34
2	1B	.000	54.312	24.728	3730	
2	1C	.823	37.546	16.435	3683	
2	2A	1.154	86.494	25.839	3741	27
2	2B	.965	46.828	28.858	3734	
2	2C	.789	37.697	21.914	3752	
2	3A	.000	4.002	3.318	3691	34
2	3B	4.213	38.387	21.085	3759	
2	3C	.788	24.187	16.144	3756	
3	1A	2.355	20.751	4.103	3609	53
3	1B	1.834	33.526	9.871	3580	
3	1C	2.576	51.848	14.332	3724	
3	2A	19.172	46.500	27.130	3739	49
3	2B	24.309	--	57.197	3754	
3	2C	44.555	--	60.987	3746	
3	3A	2.091	44.530	23.365	3720	64
3	3B	47.404	--	65.403	3759	
3	3C	8.763	22.316	51.126	3639	

Table D.21: Leaching concentrations for no-tillage/band-injected plots

Plot No.	Replication and position	Propachlor (ppb)	Atrazine (ppb)	Alachlor (ppb)	Weight (g)	Time after Rainfall begin (minutes)
1	1A	13.905	87.319	40.248	4253	45
1	1B	21.863	57.686	38.281	4276	
1	1C	5.555	45.959	25.648	4283	
1	2A	2.683	87.318	21.685	2395	50
1	3A	22.715	152.340	73.693	4281	24
1	3B	8.014	181.680	48.925	4258	
1	3C	12.342	102.996	67.808	4232	
2	1A	1.535	7.928	9.254	4221	37
2	1B	1.190	3.148	2.783	4046	
2	1C	1.332	27.739	5.306	4253	
2	2A	2.281	74.978	16.530	4208	63
2	2B	1.026	17.689	3.418	4246	
2	2C	1.270	19.709	8.342	4233	
2	3A	.994	7.765	1.703	4212	50
2	3B	.978	5.327	2.153	4223	
2	3C	.977	9.278	3.690	2417	
3	1A	1.767	20.579	9.517	3770	67
3	2A	1.054	54.745	12.445	4058	46
3	2B	6.242	38.817	36.767	4026	
3	2C	1.070	23.769	2.932	1489	
3	3A	1.633	19.382	11.613	4080	62
3	3B	.761	6.216	.769	3754	

Table D.22: Leaching concentrations for no-tillage/band-sprayed plots

Plot No.	Replication and position	Propachlor (ppb)	Atrazine (ppb)	Alachlor (ppb)	Weight (g)	Time after Rainfall begin (minutes)
1	1A	5.341	72.294	27.878	4120	19
1	1B	1.374	39.639	20.227	4106	
1	1C	32.215	40.644	44.194	4069	
1	2A	12.606	12.760	10.956	4153	35
1	2B	4.403	4.572	4.438	4059	
1	2C	2.775	3.870	3.870	4256	
1	2A	1.587	1.591	5.043	3995	25
1	2B	4.787	33.859	17.301	3889	
1	2C	5.163	56.064	36.123	4139	
2	1A	1.901	25.060	3.914	4118	46
2	1B	5.448	30.326	15.836	3525	
2	2A	6.133	215.780	48.633	4175	65
2	2B	5.799	146.452	31.634	4224	
2	2C	7.835	169.487	48.633	1225	
2	3A	5.056	188.256	60.149	2197	66
3	1A	1.468	48.292	10.647	2281	124

Table D.23: Leaching concentrations for ridge-tillage/band-injected plots

Plot No.	Replication and position	Propachlor (ppb)	Atrazine (ppb)	Alachlor (ppb)	Weight (g)	Time after Rainfall begin (minutes)
2	1A	.959	1.637	3.495	3548	40
2	1B	.945	4.921	2.655	3999	
2	1C	.000	2.691	1.239	Broke	
2	2A	.643	16.204	8.294	4012	38
2	2B	1.650	8.676	7.131	4096	
2	3A	1.399	24.141	17.952	4043	41
2	3B	12.040	27.639	18.183	3779	
2	3C	.639	13.358	10.065	3896	
3	1A	.000	2.617	1.465	4255	37
3	1B	.591	1.135	1.037	4097	
3	2A	.604	3.568	1.365	3684	48
3	2B	.634	32.408	7.830	4098	
3	2C	1.553	2.101	1.904	3723	
3	3A	5.347	25.924	3.295	4265	47
3	3B	.000	.000	14.553	4274	
3	3C	4.569	15.808	11.404	4188	

Table D.24: Leaching concentrations for ridge-tillage/band-sprayed plots

Plot No.	Replication and position	Propachlor (ppb)	Atrazine (ppb)	Alachlor (ppb)	Weight (g)	Time after Rainfall begin (minutes)
1	2A	4.131	13.760	6.593	361	95
1	3A	.000	1.694	4.883	326	67
2	1A	.000	83.080	10.220	4215	69
2	1B	3.644	37.491	8.705	292	
2	3A	.000	12.620	4.374	4133	91
2	3B	.000	12.568	1.989	4020	
2	3C	.000	23.513	2.478	3767	
3	1A	.000	.719	.000	3543	103
3	1B	.000	1.168	.000	394	
3	2A	.000	1.129	1.783	3683	117
3	2B	1.663	1.517	1.888	3521	
3	2C	1.763	2.277	1.953	705	
3	3A	2.952	44.148	5.985	3739	80
3	3B	.000	10.100	1.989	3708	
3	3C	1.755	4.331	2.567	3759	

APPENDIX E. FORTRAN PROGRAMS FOR RUNOFF AND LEACHING

```
      PROGRAM RSIMUL
*****************************************************************
*                                                               *
*  This program is used to calculate the total herbicide losses *
* from a simulated rainfall event.  Losses are determined from  *
* the water and the sediment concentration found in the runoff  *
* over the period of rainfall.  The variables used are:         *
*  TILLAG : Tillage method used on the plot                     *
*  APPL   : Herbicide application method used on the plot       *
*  REPL   : Number of the plot replication                      *
*  NSAMP  : Number of runoff sample collected during the rainfall *
*           event           *
*  AREA   : Area of a given plot (acre)          *
*  SLOPE  : Slope for a given plot (%)                           *
*  RESCOV : Percent residue cover found on the plot (%)          *
*  RUNBEG : The time the runoff began after rainfall started (min)*
*  SAMPLE : Runoff sample number                                 *
*  FLOWRT : Flowrate of the runoff water from the plot (g/s)     *
*  INTLEN : Interval length that a sample was collected (min)    *
*  SEDCON : The sediment concentration of the runoff sample (ppm) *
*  ALWAT  : Concentration of Alachlor found in the water for a   *
*           given sample (ppb)                                   *
*  ATWAT  : Concentration of Atrazine found in the water for a   *
*           given sample (ppb)                                   *
*  PRWAT  : Concentration of Propachlor found in the water for a *
*           given sample (ppb)                                   *
*  ALSED  : Concentration of Alachlor found in the sediment for a *
*           given sample (ppb)                                   *
*  ALSED  : Concentration of Atrazine found in the sediment for  *
*           given sample (ppb)                                   *
*  ALSED  : Concentration of Propachlor found in the sediment for *
*           a given sample (ppb)                                 *
*  EROS   : Erosion that took place during a given time interval *
*           (kg/ha)                                              *
*  RUNOFF : Runoff that took place during a given time interval  *
*           (cm)                                                 *
*  ALWLOS : Alachlor lost in runoff water during a time interval *
*           (g/ha)                                               *
*  ATWLOS : Atrazine lost in runoff water during a time interval *
*           (g/ha)                                               *
```

```
*  PRWLOS : Propachlor lost in runoff water during a time interval*
*           (g/ha)                                                 *
*  ALSLOS : Alachlor lost in runoff sediment during time interval *
*           (g/ha)                                                 *
*  ATSLOS : Atrazine lost in runoff sediment during time interval *
*           (g/ha)                                                 *
*  ALSLOS : Propachlor lost in runoff sediment during time        *
*           interval (g/ha)                                        *
*  ALWSUM : Cummulative atrazine lost in water (g/ha)             *
*  ATWSUM : Cummulative alachlor lost in water (g/ha)             *
*  PRWSUM : Cummulative propachlor lost in water (g/ha)           *
*  ALSSUM : Cummulative alachlor lost with soil erosion (g/ha)    *
*  ATSSUM : Cummulative atrazine lost with soil erosion (g/ha)    *
*  PRSSUM : Cummulative propachlor lost with soil erosion (g/ha)  *
*  TOTAL  : Total alachlor lost with water and sediment (g/ha)    *
*  TOTAT  : Total atrazine lost with water and sediment (g/ha)    *
*  TOTPR  : Total propachlor lost with water and sediment (g/ha)  *
*  PALLST : Percent of applied alachlor that was lost in runoff % *
*  PATLST : Percent of applied atrazine that was lost in runoff % *
*  PPRLST : Percent of applied propachlor that was lost in runoff%*
*  ALAPPL : Amount of alachlor applied (kg/ha)                    *
*  ATAPPL : Amount of atrazine applied (kg/ha)                    *
*  PRAPPL : Amount of propachlor applied (kg/ha)                  *
*  RUNSUM : Total runoff for the the rainfall event (cm)          *
*  EROSUM : Total erosion during the rainfall event (kg/ha)       *
*  SEDPPM : Flow weighted erosion (ppm)                           *
*  FWATW  : Flow weighted concentration for atrazine/water(mg/l)  *
*  FWALW  : Flow weighted concentration for alachlor/water(mg/l)  *
*  FWPRW  : Flow weighted concentration for propachlor/water(mg/l)*
*  FWATS  : Flow weighted concentration for atrazine/sediment(ppm)*
*  FWALS  : Flow weighted concentration for alachlor/sediment(ppm)*
*  FWPRS  : Flow weighted concentration for propachlor/sed. (ppm  *
*******************************************************************

INTEGER REPL, NSAMP, SAMPLE, I, J, K

        REAL AREA, SLOPE, RESCOV, INTLEN(10), FLOWRT(10), SEDCON(10),
     +      ALWAT(10), ATWAT(10), PRWAT(10), ALSED(10), ATSED(10),
     +       PRSED(10), RUNBEG, EROS(10), RUNOFF(10), SAMPN(10),
     +       ALWLOS, ATWLOS, PRWLOS, ALSLOS, ATSLOS, PRSLOS, ALWSUM,
```

```
     +        ATWSUM, PRWSUM, ALSSUM, ATSSUM, PRSSUM, TOTAL, TOTAT,
     +        TOTPR, PALLST, PATLST, PPRLST, ALAPPL, ATAPPL, PRAPPL,
     +        TARB
          CHARACTER*10 TILLAG, APPL
CHARACTER*20 INFILE, OUTFIL, ECHOUT
CHARACTER*3 ANSWER
*****************************************************
* format statement are located here for the program *
*****************************************************

   1 FORMAT(A)
   4    FORMAT(1X, A10,1X,A10,1X,I1,1X,I1)
   9    FORMAT(1X, A10,1X,A10,1X,I1,1X,I1)
  10 FORMAT(1X, F6.2,1X,F4.2,1X,F4.1,1X,F5.2)
  11    FORMAT(1X,F6.4,1X,F6.4,1X,F6.4)
  20    FORMAT(1X, I1,1X,F5.2,1X,F6.2,1X,F7.1,1X,F7.1,1X,6(F7.2,1X))
  30    FORMAT(' ',I1,1X,F8.3,1X,F8.2)
  40    FORMAT(1X, F8.6,1X,F4.2,1X,F4.1,1X,F5.2)
  50    FORMAT(' ',I1,1X,F6.2,1X,F8.3,1X,F8.2)
  60    FORMAT(' ','RAINFALL SIMULATION STUDY', 5X,
     +          'AMES, IA., AUGUST, 1990',/)
  70    FORMAT(' ',A10,1X,A10,1X,I1)
  80    FORMAT(' ','Area = ',F8.6,' ha ',' Slope = ',F3.1,' % ',
     +'Residue Cover = ',F4.1,' %')
  81    FORMAT(' ','Runoff started ',F5.2,' minutes after rainfall
     +began')
  82 format('0',10X,'Interval',14X,'Sediment')
  83    FORMAT(' ',1X,'Sample',4x,'Length',4x,'Flowrate',4x,'Conc.')
  84    FORMAT(' ',1X,'Number',5X,'(min)',5X,'(cm/s)',5X,'(ppm)')
  85    FORMAT(' ',1X,'****************************************',/)
  86    FORMAT(' ',3X,I1,7X,F4.1,6X,F6.2,5X,F7.1)
  87    FORMAT(' ','Alachlor applied = ',F6.3,' kg/ha',/,
     +1X,'Atrazine applied = ',F6.3,' kg/ha',/,
     +1X,'Propachlor applied = ',F6.3,' kg/ha')
  89    FORMAT('0',16X,'Concentration',16X,'Concentration')
  90    FORMAT(' ',1X,'Sample',8X,'(ppb in water)',14X,
     +'(ppb in sediment)')
  91    FORMAT(' ',1X,'Number',1X,'Alachlor',1X,'Atrazine',1X,
     +'Propachlor',2x,'Alachlor',1X,'Atrazine',1X,'Propachlor')
  92    FORMAT(' ','*********************************************
```

```
     +************************',/)
  93    FORMAT(' ',3X,I1,3X,F8.1,1X,F8.1,1X,F8.1,4X,F8.1,1X,F8.1,1X,
     +        F8.1)
 101    FORMAT('0',1X,9X,'Time after')
 102    FORMAT(' ',1X,'Sample',4x,'Rainfall',5X,'Runoff',3x,
     +'Erosion')
 103    FORMAT(' ',1X,'Number',3x,'Began (min)',4x,'(cm)',4x,
     +'(kg/ha)')
 104    FORMAT(' ',1X,'****************************************',/)

 105    FORMAT(' ',3X,I1,8X,F6.2,6X,F6.3,3X,F7.2)
 106    FORMAT('0',15X,'Accumulated',20X,'Accumulated')
 111    FORMAT(' ',13X,'Losses in water',15X,'Losses in sediment')
 112    FORMAT(' ',1X,'Sample',1X,'Alachlor',1X,'Atrazine',1X,
     +'Propachlor',2x,'Alachlor',1X,'Atrazine',1X,'Propachlor')
 113 FORMAT(' ',1X,'Number',2X,'(g/ha)',3X,'(g/ha)',4X,'(g/ha)',
     +5X,'(g/ha)',3X,'(g/ha)',4X,'(g/ha)')
 114    FORMAT(' ','*******************************************
     +************************',/)
 115    FORMAT(' ',3X,I1,4X,F8.4,1X,F8.4,2X,F8.4,3X,F8.4,1X,F8.4,2X,
     +        F8.4)
 116    FORMAT(' ',/,1X,'Flow weighted concentrations, ppb')
 117 FORMAT(' ',7X,F8.3,1X,F8.3,2X,F8.3,3X,F8.3,1X,F8.3,2X,F8.3,/)
 118    FORMAT(' ','Flow weighted erosion = ',F8.3,' ppm')
 201 FORMAT('0','Total alachlor losses =    ',F10.5,' g/ha',/,1x,
     +'Total atrazine losses =    ',F10.5, ' g/ha',/,1x,
     +'Total propachlor losses = ',F10.5, ' g/ha')
 202 FORMAT('0','Percent of alachlor applied lost = ',F7.3,' %',/,
     +1X,'Percent of atrazine applied lost = ',F7.3,' %',/,
     +1X,'Percent of propachlor applied lost =  ',F7.3,' %')

******************************************************
* Determine if the user has a input file already or *
* if one needs to be created                         *
******************************************************

WRITE(*,*) ' IS THE DATA FILE ALREADY ESTABLISHED? YES OR NO '
READ(*,1) ANSWER
*******************************************************
* input file already available.  create an echo file *
```

```
* and an output file                                  *
*******************************************************

IF (ANSWER .EQ. 'YES') THEN
WRITE(*,*) ' ENTER THE NAME OF THE INPUT FILE *.DAT'
READ(*,1) INFILE
* WRITE(*,*) ' ENTER NAME: ECHO CHECK OUTPUT DATA FILE :'
* READ(*,1) ECHOUT
*        WRITE(*,*) ' ENTER THE NAME OF THE OUTPUT DATA FILE : '
* READ(*,1) OUTFIL

****************************************
* open the files for input and output  *
****************************************

OPEN(UNIT=1,FILE=INFILE//'.DAT',STATUS='OLD')
OPEN(UNIT=2,FILE=INFILE//'.ECH',STATUS='NEW')
OPEN(UNIT=3,FILE=INFILE//'.OUT',STATUS='NEW')

****************************************************
* read in the known variables from the input file  *
****************************************************

READ(1,4) TILLAG, APPL, REPL, NSAMP
         READ(1,*) AREA, SLOPE, RESCOV, RUNBEG
READ(1,*) PRAPPL, ATAPPL, ALAPPL

DO 110 I = 1, NSAMP
READ(1,*)  SAMPN(I), INTLEN(I), FLOWRT(I),
     +          SEDCON(I), ALWAT(I), ATWAT(I), PRWAT(I),
     +                 ALSED(I), ATSED(I), PRSED(I)
  110 CONTINUE

ELSE

****************************************************
* no input file is available, create an input file *
* and do an echo check                             *
****************************************************
```

```
WRITE(*,*) ' ENTER NAME: ECHO CHECK OUTPUT DATA FILE :'
READ(*,1) ECHOUT
        WRITE(*,*) ' ENTER THE NAME OF THE OUTPUT DATA FILE : '
READ(*,1) OUTFIL

OPEN(UNIT=2,FILE=ECHOUT,STATUS='NEW')
OPEN(UNIT=3,FILE=OUTFIL,STATUS='NEW')

****************************************
* Input the initial plot characteristic*
****************************************

WRITE(*,*) 'INPUT TILLAGE, APPL, REPL, # OF SAMPLES'
READ(*,*) TILLAG, APPL, REPL, NSAMP
WRITE(*,*) 'INPUT AREA, SLOPE, RESCOV, RUNBEG'
         READ(*,*) AREA, SLOPE, RESCOV, RUNBEG
WRITE(*,*) 'INPUT PRAPPL, ATAPPL, ALAPPL'
READ(*,*) PRAPPL, ATAPPL, ALAPPL

***************************************************
* input the water and sediment concentrations for *
* the collected runoff                            *
***************************************************

DO 100 I = 1, NSAMP
WRITE(*,*) 'INPUT  INTLEN, FLOWRT, SEDCON, PRWAT,
     + ATWAT, ALWAT FOR SAMPLE', I
  READ(*,*) INTLEN(I), FLOWRT(I), SEDCON(I),
     +          PRWAT(I), ATWAT(I), ALWAT(I)

***************************************************
* flowrt (g/s), intlen (min), sedcon (ppm) alwat, *
* atwat,& prwat (ppb)                             *
***************************************************

ALSED(I) = ALWAT(I) * 2.4
ATSED(I) = ATWAT(I) * 3.2
PRSED(I) = PRWAT(I) * 8.2

 100 CONTINUE
```

```
        END IF

***************************
*  convert ft^2 to hectares *
***************************

HECT = AREA/43560.0*0.40469

*****************************
*  Echo check of input values *
*****************************

WRITE(2,9) TILLAG, APPL, REPL, NSAMP
  WRITE(2,10) AREA, SLOPE, RESCOV, RUNBEG
                WRITE(2,11) PRAPPL, ATAPPL, ALAPPL

DO 200 J = 1, NSAMP
                WRITE(2,20) J, INTLEN(J), FLOWRT(J), SEDCON(J),
     +     ALWAT(J), ATWAT(J), PRWAT(J), ALSED(J), ATSED(J), PRSED(J)
 200 CONTINUE

***************************************************
* output the input information to the output file *
***************************************************

WRITE(3,60)
WRITE(3,70)TILLAG,APPL,REPL
WRITE(3,80)HECT,SLOPE,RESCOV
WRITE(3,87)ALAPPL, ATAPPL, PRAPPL
WRITE(3,81)RUNBEG
WRITE(3,*)
WRITE(3,82)
WRITE(3,83)
WRITE(3,84)
        WRITE(3,85)

DO 300 J = 1, NSAMP
                WRITE(3,86) J, INTLEN(J), FLOWRT(J), SEDCON(J)
 300 CONTINUE
```

```
**************************************************************
* print out the herbicide losses in runoff water and sediment*
**************************************************************

WRITE(3,89)
WRITE(3,90)
WRITE(3,91)
WRITE(3,92)

DO 350 J = 1, NSAMP
WRITE(3,93) J, ALWAT(J), ATWAT(J), PRWAT(J), ALSED(J),
     +           ATSED(J), PRSED(J)
  350  CONTINUE

***********************************************************
* print out the headings for the runoff and erosion values*
***********************************************************

WRITE(3,101)
WRITE(3,102)
WRITE(3,103)
        WRITE(3,104)

*****************************************************
* intitialize all variables to 0.0 before iteration  *
*****************************************************

        TARB = RUNBEG
EROSUM = 0.0
RUNSUM = 0.0
ALSSUM = 0.0
ATSSUM = 0.0
PRSSUM = 0.0
ALWSUM = 0.0
ATWSUM = 0.0
PRWSUM = 0.0
        ATSLOS = 0.0
ALSLOS = 0.0
PRSLOS = 0.0
```

```
      ATWLOS = 0.0
      ALWLOS = 0.0
      PRWLOS = 0.0
      EROSUM = 0.0
      RUNSUM = 0.0

      DO 400 K = 1, NSAMP

************************************************************
* calculate the time after rainfall began that this sample *
* was taken (min).                                         *
************************************************************
      TARB = TARB + INTLEN(K)

******************************************************************
* calculate the erosion that takes place during each time interval*
* (kg/ha).                                                        *
* (g/s * s * 1kg/1000g) / ha = kg/ha                              *
******************************************************************

      EROS(K) = (FLOWRT(K)*INTLEN(K)*60.0*SEDCON(K)/1000000.0*
     +                    0.001)/HECT

      EROSUM = EROSUM + EROS(K)

******************************************************************
* calculate the runoff that occurs during each time interval (cm)*
* (g/s * s * ft^3/62.4lb * lb/453.6g * 12in/ft * 2.54cm/in)      *
* / ft^2 = cm                                                    *
******************************************************************

      RUNOFF(K) =(FLOWRT(K)*INTLEN(K)*60.0*(1.0-SEDCON(K)/
     +                    1000000.0)/62.4/453.6*12.0*2.54)/AREA

      RUNSUM = RUNSUM + RUNOFF(K)

      WRITE(3,105) K, TARB, RUNOFF(K), EROS(K)
  400 CONTINUE

***********************************************************
```

```
* print out the table headings for the accumulative        *
herbicide losses in the water and in the sediment (g/ha)   *
************************************************************

WRITE(3,106)
WRITE(3,111)
WRITE(3,112)
WRITE(3,113)
     WRITE(3,114)

  DO 500 K = 1, NSAMP
*********************************************************************
* calculate the herbicide lost with runoff water (g/ha) during each*
* time interval.  Note the conversion factors.                     *
* [ppb * cm * (1 ppm/1000 ppb) * (100 g/ha-cm / 1 ppm)] = g/ha     *
*********************************************************************

ALWLOS = ALWAT(K) * RUNOFF(K) * 0.1
                ATWLOS = ATWAT(K) * RUNOFF(K) * 0.1
PRWLOS = PRWAT(K) * RUNOFF(K) * 0.1

*******************************************************************
* calculate the herbicide lost with soil erosion during each time*
* interval (g/ha).  Note the conversion factors.                 *
* (kg/ha * 1000g/kg * 1part/1000000000 = g/ha                    *
*******************************************************************

ALSLOS = ALSED(K) / 1000000.0 * EROS(K)
ATSLOS = ATSED(K) / 1000000.0 * EROS(K)
PRSLOS = PRSED(K) / 1000000.0 * EROS(K)

*****************************************************************
* add the herbicide water losses over the rainfall event (g/ha)*
*****************************************************************

ALWSUM = ALWSUM + ALWLOS
ATWSUM = ATWSUM + ATWLOS
PRWSUM = PRWSUM + PRWLOS

************************************************
```

```
* add the herbicide sediment losses over the   *
* rainfall event (g/ha)                        *
************************************************

ALSSUM = ALSSUM + ALSLOS
ATSSUM = ATSSUM + ATSLOS
PRSSUM = PRSSUM + PRSLOS


WRITE(3,115) K, ALWSUM, ATWSUM, PRWSUM, ALSSUM, ATSSUM,
     +                      PRSSUM

 500 CONTINUE

**************************************************
* calculate the flow weighted concentrations for *
* the water and sedient                          *
**************************************************

SEDLOS = EROSUM * HECT

*******************************************
* sedlos (kg) = erosum (kg/ha) * hect (ha)*
*******************************************

WATLOS = RUNSUM * HECT * 100000.0

*********************************************************
* watlos (kg) = runsum (cm) * hect (ha) * (kg/ha-10cm)  *
* / (1/1000000)                                         *
*********************************************************

SEDPPM = SEDLOS / (WATLOS + SEDLOS) * 1000000.0

************************************************************
* fwalw (ppb) = [alwsum (g/ha)/ runsum (cm)]* 1kg/1000g *  *
1000ppm/(1kg * /ha-10cm)                                   *
************************************************************

FWALW = ALWSUM / RUNSUM * 10.0
```

```
      FWATW = ATWSUM / RUNSUM * 10.0
      FWPRW = PRWSUM / RUNSUM * 10.0

************************************************************
* fwals (ppb) = [alssum (g/ha) / erosum (kg/ha)] * 1kg/1000g * *
* 1000000000                                                 *
************************************************************

      FWALS = ALSSUM / EROSUM * 1000000.0
      FWATS = ATSSUM / EROSUM * 1000000.0
      FWPRS = PRSSUM / EROSUM * 1000000.0

      WRITE(3,116)
      WRITE(3,117) FWALW, FWATW, FWPRW, FWALS,
     +                          FWATS, FWPRS
      WRITE(3,118) SEDPPM

*****************************************************************
* calculate the total herbicide lost in water and sediment during *
* during the rainfall event                                        *
*****************************************************************
      TOTAL = ALWSUM + ALSSUM
      TOTAT = ATWSUM + ATSSUM
      TOTPR = PRWSUM + PRSSUM

      WRITE(3,201) TOTAL, TOTAT, TOTPR

*****************************************************************
* calculate the percent of each herbicide lost in runoff water and*
* sediment as a percent of that which was originally applied      *
*****************************************************************

      PALLST = TOTAL / (ALAPPL * 1000.0) * 100.0
      PATLST = TOTAT / (ATAPPL * 1000.0) * 100.0
      PPRLST = TOTPR / (PRAPPL * 1000.0) * 100.0

      WRITE(3,202) PALLST, PATLST, PPRLST

******************************
* close the output files     *
```

```
*******************************

CLOSE(UNIT=2)
CLOSE(UNIT=3)

*******************************
* Have the program stop here   *
*******************************
STOP
END
```

```
PROGRAM LEACH
*************************************************************
*                                                     *
* This progam calculates the volume of leachate that moves *
* through a plot of a given soil volume during a rainfall  *
* event.  The variables for this progam are as follows:    *
*                                                     *
*   DRV : Depth of drainage water (cm  )                   *
*  RAIN : Depth of rain water during rainfall (cm)         *
*RUNOFF : Depth of runoff from rainfall event (cm)         *
*  SV   : Soil volume for a given layer (ft^3)             *
*  BD   : Bulk density in each layer (g/cm^3)              *
*  MW(I): Gravimetric moisture content of each layer,      *
*   post event (%)                                     *
*  MD(I): Gravimetric moisture content of each layer,      *
*         pre-event (%)                                    *
*************************************************************

REAL DRV, RAIN, RUNOFF, SV, BD, MW(4), MD(4), SUM, SVM

INTEGER I, J, K, NUMLAY

CHARACTER*7 DEPTH1, DEPTH2, DEPTH3, PLOT

WRITE(*,*) 'INPUT THE PLOT NAME, EX. NTBS1'
READ(*,*)PLOT
WRITE(*,*) 'INPUT THE RAIN DEPTH FOR THE RAIN EVENT (cm)'
READ(*,*) RAIN
WRITE(*,*) 'INPUT THE RUNOFF DEPTH (cm)'
READ(*,*) RUNOFF
WRITE(*,*) 'INPUT THE NUMBER OF LAYERS'
READ(*,*) NUMLAY

* WRITE(*,*) 'INPUT THE SOIL VOLUME FOR EACH LAYER (ft^3)'
* READ(*,*) SV
SV = 225.0
SV = SV * (12.0**3) * (2.54**3)
                SVM = SV * 0.02831685
```

```
* WRITE(*,10)
*  10 FORMAT(' ','INPUT THE BULK DENSITY FOR EACH ',
*     +'LAYER, g/cm^3')
* READ(*,*) BD
BD = 1.34

DO 200 I = 1, NUMLAY

WRITE(*,20) I
   20 FORMAT(' ','INPUT THE PRE-GRAVIMETRIC MC FOR LAYER ',
     +I1,'(%)')
READ(*,*) MD(I)
  200 CONTINUE

DO 300 I = 1, NUMLAY

WRITE(*,30) I
   30 FORMAT(' ','INPUT THE POST-GRAVIMETRIC MC FOR LAYER ',
     +I1,'(%)')
READ(*,*) MW(I)
  300 CONTINUE

SUM = 0.0

DO 400 J = 1, NUMLAY
SUM = SUM + SV * BD * ((MW(J)-MD(J))/100.0)
  400 CONTINUE

SUM = SUM / (150.0 * 144.0 * 6.452)

PRINT*,'SUM = ', SUM
DRV = RAIN - RUNOFF - SUM

WRITE(*,40) DRV
   40 FORMAT(' ','DEPTH OF DRAINAGE WATER, CM= ',F5.1)

OPEN (UNIT=1,FILE=PLOT//'.LOT',STATUS='NEW')
```

```
      DEPTH1 = ' 0 - 15'
      DEPTH2 = '15 - 30'
      DEPTH3 = '30 - 45'

  49  FORMAT('0',1X,'PLOT - ',A7,/)
  50  FORMAT(' ',1X,'Layer',3X,'Layer ',3X, ' Bulk  ',1X,
     +'Pre-rain',1X,'Post-rain')
  51  FORMAT(' ',1X,'Depth',3X,'Volume',3X, 'Density',1X,
     +'  M. C. ',1X,'  M. C.  ')
  52  FORMAT(' ',1X,' cm  ',3X,' m^3  ',3X,  'g/cm^3 ',1X,
     +'    %   ',1X,'    %    ')
  53  FORMAT(' ','*****************************************',
     +'***********',/)
  60  FORMAT(' ',A7,1X,F8.1,3X,F4.1,5X,F4.1,5X,F4.1)
  61  FORMAT('0','THE DEPTH OF RAINFALL WATER = ',F6.2,' cm')
  62  FORMAT(' ','THE DEPTH OF RUNOFF WATER   = ',F6.2,' cm')
  63  FORMAT(' ','THE DEPTH OF DRAINAGE WATER = ',F6.2,' cm')

      WRITE(1,49)PLOT
      WRITE(1,50)
      WRITE(1,51)
      WRITE(1,52)
      WRITE(1,53)

      WRITE(1,60) DEPTH1, SVM, BD, MD(1), MW(1)
      WRITE(1,60) DEPTH2, SVM, BD, MD(2), MW(2)
      WRITE(1,60) DEPTH3, SVM, BD, MD(3), MW(3)

      WRITE (1,61) RAIN
      WRITE (1,62) RUNOFF
      WRITE (1,63) DRV

      CLOSE(1)
      STOP
      END
```

APPENDIX F. NON-LINEAR CURVE FITTING RESULTS FOR THE RUNOFF DATA

Table F.1: Non-linear curve fitting results for alachlor in runoff water

Tillage Method	Application Method	Replication	A	B	r**2
CT	BI	1	22.5	-0.025	0.83
CT	BI	2	29.8	-0.010	0.19
CT	BI	3	21178.5	-0.148	0.90
CT	BS	1	598.5	-0.056	0.94
CT	BS	2	36.3	-0.002	0.02
CT	BS	3	1974.2	-0.043	0.94
NT	BI	1	328.7	-0.002	0.03
NT	BI	2	70.1	-0.013	0.68
NT	BI	3	28.9	-0.003	0.18
NT	BS	1	106.9	-0.003	0.02
NT	BS	2	117.9	-0.010	0.21
NT	BS	3	380.1	-0.021	0.91
RT	BI	1	42.5	-0.006	0.20
RT	BI	2	218.4	-0.033	0.87
RT	BI	3	31.8	-0.009	0.44
RT	BS	1	203.0	-0.024	0.93
RT	BS	2	118.9	-0.010	0.98
RT	BS	3	53.0	-0.004	0.04

Table F.2: Non-linear curve fitting results for alachlor in runoff sediment

Tillage Method	Application Method	Replication	A	B	r**2
CT	BI	1	4237.4	-0.038	0.76
CT	BI	2	1997.0	-0.004	0.02
CT	BI	3	24079.0	-0.045	0.71
CT	BS	1	7168.4	-0.008	0.12
CT	BS	2	1377.0	0.0001	0.00
CT	BS	3	34570.0	-0.042	0.92
NT	BI	1	5646.0	0.002	0.00
NT	BI	2	19774.0	-0.002	0.46
NT	BI	3	3549.0	0.021	0.82
NT	BS	1	17026.0	-0.011	0.12
NT	BS	2	4217.0	0.022	0.73
NT	BS	3	4212.0	0.012	0.18
RT	BI	1	3948.0	0.007	0.21
RT	BI	2	2399.0	-0.003	0.06
RT	BI	3	1438.0	0.003	0.06
RT	BS	1	5014.0	-0.017	0.15
RT	BS	2	730.9	0.006	0.07
RT	BS	3	2768.2	-0.007	0.11

Table F.3: Non-linear curve fitting results for atrazine in runoff water

Tillage Method	Application Method	Replication	A	B	r**2
CT	BI	1	46.0	-0.032	0.93
CT	BI	2	232.8	-0.033	0.93
CT	BI	3	6938.0	-0.078	0.96
CT	BS	1	1115.0	-0.054	0.94
CT	BS	2	122.6	-0.002	0.04
CT	BS	3	5147.0	-0.050	0.94
NT	BI	1	792.3	-0.008	0.47
NT	BI	2	707.2	-0.038	0.99
NT	BI	3	134.1	-0.022	0.92
NT	BS	1	202.1	-0.008	0.11
NT	BS	2	281.8	-0.007	0.25
NT	BS	3	1906.0	-0.049	0.98
RT	BI	1	396.4	-0.014	0.86
RT	BI	2	422.4	-0.032	0.98
RT	BI	3	100.8	-0.016	0.76
RT	BS	1	945.9	-0.060	0.83
RT	BS	2	243.7	-0.013	0.73
RT	BS	3	203.9	-0.015	0.78

Table F.4: Non-linear curve fitting results for atrazine in runoff sediment

Tillage Method	Application Method	Replication	A	B	r**2
CT	BI	1	10022.5	-0.085	0.82
CT	BI	2	39946.7	-0.060	0.81
CT	BI	3	10328.0	-0.022	0.47
CT	BS	1	1571.5	-0.005	0.19
CT	BS	2	1069.7	0.007	0.44
CT	BS	3	845.4	0.007	0.05
NT	BI	1	7922.0	-0.008	0.47
NT	BI	2	16071.7	-0.018	0.09
NT	BI	3	3026.0	0.033	0.95
NT	BS	1	54168.0	-0.014	0.18
NT	BS	2	2078.1	0.035	0.97
NT	BS	3	8384.0	0.006	0.06
RT	BI	1	3061.0	-0.010	0.26
RT	BI	2	7921.0	-0.030	0.70
RT	BI	3	3107.0	-0.015	0.57
RT	BS	1	7111.2	-0.025	0.44
RT	BS	2	1307.0	0.006	0.19
RT	BS	3	6320.3	-0.065	0.86

Table F.5: Non-linear curve fitting results for propachlor in runoff water

Tillage Method	Application Method	Replication	A	B	r**2
CT	BI	1	1.7	-0.009	0.31
CT	BI	2	2.6	0.001	0.00
CT	BI	3	57.5	-0.062	0.78
CT	BS	1	-	-	-
CT	BS	2	0.7	0.020	0.33
CT	BS	3	168.4	-0.040	0.15
NT	BI	1	108.0	0.001	0.00
NT	BI	2	1.0	0.007	0.25
NT	BI	3	2.2	0.007	0.35
NT	BS	1	18.6	-0.001	0.00
NT	BS	2	5.0	0.0003	0.00
NT	BS	3	62.5	-0.018	0.30
RT	BI	1	1.0	0.003	0.03
RT	BI	2	1.2	-0.008	0.10
RT	BI	3	1.4	0.001	0.01
RT	BS	1	7.0	0.009	0.14
RT	BS	2	43.2	-0.017	0.69
RT	BS	3	6.4	-0.004	0.02

Table F.6: Non-linear curve fitting results for propachlor in runoff sediment

Tillage Method	Application Method	Replication	A	B	r**2
CT	BI	1	-	-	-
CT	BI	2	1027.8	0.001	0.00
CT	BI	3	65543.0	-0.090	0.77
CT	BS	1	3445.0	-0.010	0.16
CT	BS	2	79.4	0.019	0.18
CT	BS	3	291.4	0.001	0.00
NT	BI	1	3104.0	-0.010	0.04
NT	BI	2	4743.0	-0.020	0.25
NT	BI	3	2329.0	0.009	0.40
NT	BS	1	6629.0	-0.050	0.34
NT	BS	2	1060.2	0.022	0.80
NT	BS	3	1281.0	0.030	0.89
RT	BI	1	2819.7	0.010	0.61
RT	BI	2	-	-	-
RT	BI	3	-	-	-
RT	BS	1	3725.0	0.009	0.26
RT	BS	2	1884.0	0.014	0.56
RT	BS	3	1494.0	0.026	0.92